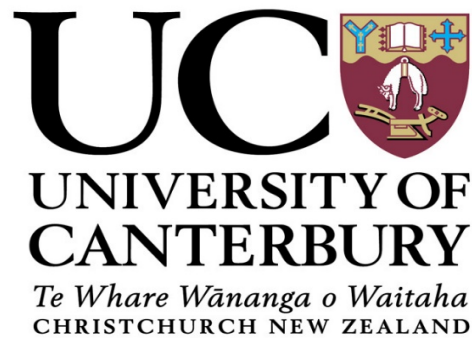


Shoulder injuries of cricket fast bowlers in New Zealand



A thesis submitted to the University of Canterbury in fulfilment of the requirements for the
degree of Doctor of Philosophy (PhD)

School of Health Sciences
College of Education, Health and Human Development
University of Canterbury
New Zealand

Sibi Boycott Noel Walter

March 2020

Statement of originality

The thesis contains no material which has been accepted for an award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to the final version of my thesis being available worldwide when deposited in the University's research repository.

Sibi Boycott Noel Walter

Date signed: 20th March 2020

Acknowledgement of collaboration

I, hereby certify that the work embodied in this thesis has been done with approval and collaboration with other organisations, I have included a copy of the involved organisation's approval in the appendix chapter of the thesis.

Sibi Boycott Noel Walter

Date signed: 20th March 2020

I, Carl Petersen attest that the research completed within this thesis by the candidate Sibi Walter, was completed with approval and collaboration with the following organisations:

- New Zealand Cricket, Lincoln



Supervisor: Carl Petersen (PhD)

Date signed: 20th March 2020

Acknowledgements

The most important person who made this PhD materialise was my supervisor, Dr Carl Petersen. I am deeply thankful to you from the bottom of my heart, for accepting, supervising and steering me all these years. I thank you for helping me make the right connections in the field and providing me with so many opportunities time and again, to build my academic career. I have learnt lots of sports science because of you. Thanks a ton, Carl. You are a blessing from God.

I would like to thank my supervisor, Dr Arindam Basu. Every meeting with you was enlightening me to the unknown world of epidemiology. I also thank you for guiding me on all parts of the methodology in this PhD thesis.

I thank Dr Richard Light for funding part of my PhD. I also thank Dr Jenny Clarke for all your support and career opportunities during these years.

A huge thanks to Bryan Stronach and Dayle Shackel from New Zealand Cricket, Gary Stead and Brendon Donkers from Canterbury Cricket, Lance Hamilton from Central Districts Cricket, Peter Zanzottera from Northern Districts Cricket, Simon Forde from Otago Cricket, Glenn Pocknall from Wellington Cricket and Brendon Wilson from Auckland Cricket for your cooperation with me to conduct the cricket injury surveillance. Thanks to Tim Braid, Ben Rapson, Dan Vann and Nathan Brown for helping me in the cricket studies.

Many thanks to Steve Hamilton, Craig Menzies, Ryan Stewart, Cameron Dear and Liam Grange and all the Noel's guys for the great support during those years.

The most important reason why I'm able to do a PhD is because of my Mom and Dad; if not for your discipline and support Mom, I would have been stuck far below in the education ladder. Thanks, Mom.

Amongst all the demands of life, I was able to balance it all only because of my loving wife Sally, if not for your love, support and cooperation nothing would have been possible, you are the greatest blessing God has given in my life. Love you and thank you. Cheers to my loving daughter Kimberly, your birth changed my life in the best possible way.

All glory, honour and praise to my Lord and Saviour, Jesus Christ.

Research outputs resulting from this thesis

Manuscripts submitted

Walter, S., Petersen, C., & Basu, A. (Under review) Effect of a 6-week Indian clubbelt strengthening programme on cricket fast bowlers' shoulder muscle strength and range of motion (*Journal of Shoulder and Elbow Surgery*).

Walter, S., Petersen, C., & Basu, A. (Under review) Analysis of cricket-related injury entitlement claims among New Zealand population over a 12-year period (*Sports Medicine Open Access*).

Walter, S., Petersen, C., & Basu, A. (Under review) International cricket injury surveillance: A media-based injury report on the ICC Cricket World Cup 2015 (*The Journal of Sports and Exercise Science*).

Conference presentations

Walter, S., Petersen, C., & Basu, A. (2019). Effect of a 6-week Indian clubbelt strength programme on fast bowlers' shoulders. *World Congress of Science and Medicine in Cricket Conference, England*.

Walter, S., Petersen, C., & Basu, A. (2017). Identifying shoulder injuries among New Zealand Cricket fast bowlers: A 12-month retrospective injury surveillance. *Sports and Exercise Science Conference, New Zealand*.

Walter, S., & Petersen, C. (2016). Media-based injury surveillance from the 2015 Cricket World Cup. *Sports Medicine Conference, New Zealand*.

Walter, S., & Petersen, C. (2015). Cricket pace bowlers shoulder injuries: a systematic literature review and suggestions for prevention. *World Congress of Science and Medicine in Cricket Conference, Australia*.

Published abstracts

Walter, S., Petersen, C., & Basu, A. (2017). Identifying shoulder injuries among New Zealand Cricket fast bowlers: A 12-month retrospective injury surveillance. *The Journal of Sports and Exercise Science*.

Walter, S., & Petersen, C. (2016). Media-based injury surveillance from the 2015 Cricket World Cup. *New Zealand Journal of Sports Medicine*.

Abstract

Cricket is predominantly a summer sport enjoyed by all age groups and has a high participation rate, across the globe. The likelihood for injury exposure is high, given the popularity of playing cricket. Therefore, injury surveillance is essential to quantify and subsequently design preventive measures to reduce injury prevalence. The studies encompassing this thesis were conducted according to van Mechelen's sports injury prevention model. The first three studies identified and quantified the extent and aetiology of cricket injuries across different performance levels, and the remaining two studies introduced preventive measures.

The first study quantified and classified cricket-related injuries in the resident New Zealand population. Cricket-related injury claim data from 2005-2016, were obtained from New Zealand's Accident Compensation Corporation and classified by injured body area, injury type and diagnosis. Based on the NZ population censuses, the age-standardised injury incidence (ASII) per 10,000 people-years was calculated using the Segi world standard for each calendar year. Results showed that the ASII for cricket injuries increased by 42% over the 12 year period. The hand/wrist (19.7 %), back/spine (15.7%) and shoulder (11.2%) were the three most injured body parts. Soft tissue injuries (76%) were the most prevalent injury, and 69% of all injuries were due to contact. The 31% non-contact injuries are likely due to repetitive and strenuous movements. One limitation of this study was that the injury onset was described generically rather than linking it to a specific cricket activity. The spine and shoulder areas experienced the greatest increase in injury prevalence over the 12 years, so it could be argued that soft tissue injuries to the spine and shoulder require special attention.

The second study aimed to identify the most common activity being undertaken during injury onset in elite cricketers. This was achieved by analysing the results of media-based injury surveillance conducted during the 2015 Cricket World Cup (CWC) One-Day Tournament. During the 49 tournament matches, a total of 31 injuries were recorded. Of these, fast bowlers (12) and batsmen (11) had a similar number of injuries, but fast bowlers missed eight more matches (31) than batsmen (23). Among the 219 tournament players, nine (4%) were injured while bowling in matches, nine (4%) were injured during training and six (3%) while batting in matches.

In the results of study 1, it was identified that shoulders were one of the most commonly injured body parts and injuries were mostly due to non-contact repetitive strenuous movement. While in study 2, it was identified that fast bowling was a highly injury-prone cricketing position. Amongst existing cricket injury studies, very few explore shoulder injuries. So the third study was aimed at finding out where fast bowlers get injured and to identify the specific diagnoses of those injuries. Hence, study 3 was conducted using retrospective 12-month injury surveillance of 35 domestic New Zealand fast bowlers. These fast bowlers had an injury prevalence of 71% (25/35). The four most injury-prone areas were the lower back (19%), ankle/feet (15%), thigh (15%) and the shoulders (13%). The injury-specific diagnoses for the 13% shoulder injuries involved the rotator cuff and the subacromial space.

Stages 1 and 2 of the sports injury prevention model proposed by van Mechelen recommends quantification of injury extent and identifying its aetiology. The results of studies 1-3 highlighted the extent of cricket-related shoulder injury prevalence and identified the fast bowling position as the most injury-prone while describing the most common injury diagnoses for elite fast bowlers.

Repetitive bowling and throwing involve shoulder abduction and rotation. The rotator cuff muscles are the primary agonists for shoulder abduction and rotation. High bowling and throwing workloads combined with decreased rest periods weakens the rotator cuff muscle strength and affects glenohumeral stability. Asymmetries in glenohumeral range of motion and rotator cuff muscle strength can lead to anatomical changes in the shoulder joint which can manifest as chronic shoulder pain. Assessment of range of motion and rotator cuff muscle strength may identify the shoulder joint's functional restrictions and potentially could be used to predict injury risk.

Study 4 measures aimed at comparing the glenohumeral range of motion (ROM) and shoulder-rotator muscle strength between fast bowlers with and without shoulder pain. Subjective reporting and objective screening were undertaken for shoulder pain, while shoulder rotators muscle strength and glenohumeral rotational ROM was measured. Overall, 35% of fast bowlers experienced shoulder pain, and these bowlers exhibited a slight trend of lower ROM in comparison to their uninjured counterparts; IR ROM (injured $76 \pm 8^\circ$, uninjured $79 \pm 9^\circ$); ER ROM (injured $81 \pm 12^\circ$, uninjured $86 \pm 5^\circ$). Regardless of a shoulder injury, all bowlers exhibited slightly weaker external rotators in comparison to their internal rotators on their

dominant side (IR, 42 ± 8 N.m; ER 39 ± 6 N.m). Although there was not a significant difference in strength between the internal and external rotators, previous shoulder injury research literature suggests that weaker external rotators are associated with the superior-anterior translation of the humerus and reduction in subacromial space. Strengthening the rotator cuff will help restore glenohumeral stability, resist humeral translation and limit subacromial impingement.

Stage 3 of van Mechelen's model suggests the introduction of preventive measures aimed at reducing injury occurrence. Therefore, a shoulder exercise programme was designed to strengthen the rotator cuff, which may potentially help prevent shoulder injuries. Study 5's objective was to observe the effects of a 6-week Indian clubbell (ICB) exercise programme on shoulder range of motion and isometric muscle strength of fast bowlers. A total of 21 healthy male fast bowlers were pair-matched on their initial shoulder-rotator isometric muscle strength (IMS) and assigned to either an ICB shoulder strengthening group or a cricket training only group. The ICB group underwent a 6-week shoulder-rotator strengthening programme. Bilateral internal rotators IMS increased in the ICB group from baseline to week 6 ($P < 0.05$). The ICB group's non-dominant arm internal rotation (IR) ROM also increased ($64 \pm 10^\circ$ to $70 \pm 6^\circ$, $P < 0.05$), while the posterior shoulder tightness decreased ($31 \pm 4^\circ$ to $37 \pm 3^\circ$, $P < 0.05$). There was no significant increase in the external rotator's strength. Rotator cuff strength is vital for positioning the humeral head in the glenohumeral joint. Stronger internal rotators and weaker external rotators may also cause superior-anterior translation of the humeral head. Thereby reducing the subacromial space and leading to impingement of its soft tissues. To create an effective shoulder injury prevention programme, the focus has to be on strengthening the shoulder rotators with special attention given to the external rotators.

In summary, study 1 identified that non-contact shoulder injuries in cricket occur mostly due to repetitive and strenuous movements. Study 2 found that fast bowling was the main activity during the onset of injuries. Study 3 revealed that fast bowler's shoulder injuries involve the rotator cuff and subacromial space. Study 4 assessed the shoulders of injured fast bowlers and lastly study 5 introduced an exercise programme to strengthen the rotator cuff and potentially reduce shoulder injuries. All these thesis studies were conducted according to the stages proposed by van Mechelen's sports injury prevention model. The first three studies quantified the extent of the problem pertaining to cricket-related shoulder injuries and established injury aetiology. The last two studies investigated and introduced preventive measures aimed at

reducing shoulder injuries. Future research should seek to conduct long term injury surveillance among fast bowlers to correlate shoulder injury incidence with an Indian clubbell exercise programme, and this would tie into the recommendation of stage 4 of the sports injury prevention model. Based on the beneficial outcomes of study 5, regular participation in an Indian clubbell exercise programme will help maintain shoulder ROM and strengthen the rotator cuff. Future investigation is required to assess the hypothesis that this will reduce shoulder overuse injury incidence.

Table of contents

Statement of originality

Acknowledgement of collaboration

Acknowledgements

Abstract

Table of contents

List of tables

List of figures

List of abbreviations and nomenclature

1. Introduction

1.1. Background information-----	2
1.2. Statement of the problem-----	4
1.3. Thesis objectives-----	5
1.4. Significance of the research-----	6

2. Review of literature

2.1. Introduction-----	9
2.2. Review of cricket injury surveillance -----	10
2.3. Anatomy of the shoulder joint-----	20
2.4. Common cricketing shoulder injuries-----	23
2.5. Throwing and fast bowling in cricket-----	27
2.6. Pathomechanism of cricket shoulder injuries-----	30
2.7. Exercise-based shoulder injury prevention-----	35

3. Studies

3.1. Preface- To determine how many cricket-related injuries are occurring among New Zealand's general population-----	39
3.1.1. Study 1. Cricket injuries in New Zealand: A review of twelve years of Accident Compensation Corporation injury entitlement claims-----	40
3.1.1.1. Abstract-----	40
3.1.1.2. Introduction-----	41
3.1.1.3. Methods-----	43
3.1.1.4. Results-----	47
3.1.1.5. Discussion-----	52
3.1.1.6. Conclusion-----	56
3.2. Preface-To determine what elite cricketers are doing at the time of injury onset----	57
3.2.1. Study 2. International cricket injury surveillance: A media-based injury report on the ICC Cricket World Cup 2015-----	58
3.2.1.1. Abstract-----	58
3.2.1.2. Introduction-----	59
3.2.1.3. Methods-----	61
3.2.1.4. Results-----	63
3.2.1.5. Discussion-----	66
3.2.1.6. Conclusion-----	69
3.3. Preface- To determine where and how elite fast bowlers are getting injured-----	71
3.3.1. Study 3. Quantifying injuries among New Zealand cricket fast bowlers: A 12-month retrospective injury surveillance -----	72
3.3.1.1. Abstract-----	72
3.3.1.2. Introduction-----	73
3.3.1.3. Methods-----	75
3.3.1.4. Results-----	77
3.3.1.5. Discussion-----	80
3.3.1.6. Conclusion-----	84

3.4. Preface-To determine the differences in the shoulder joint's range of motion and muscle strength between injured and uninjured fast bowlers-----	85
3.4.1. Study 4: Comparison of shoulder muscle strength and range of motion between fast bowlers with and without shoulder injury-----	87
3.4.1.1. Abstract-----	87
3.4.1.2. Introduction-----	88
3.4.1.3. Methods-----	91
3.4.1.4. Results-----	93
3.4.1.5. Discussion-----	94
3.4.1.6. Conclusion-----	98
3.5. Preface- To investigate the effects of an exercise programme on rotator cuff muscle strength and shoulder rotational range of motion-----	99
3.5.1. Study 5: Effect of a 6-week Indian clubbell strengthening programme on cricket fast bowlers' shoulder muscle strength and range of motion-----	100
3.5.1.1. Abstract-----	100
3.5.1.2. Introduction-----	101
3.5.1.3. Methods-----	103
3.5.1.4. Results-----	105
3.5.1.5. Discussion-----	107
3.5.1.6. Conclusion-----	109
4. Discussion:	
4.1. Overview of the thesis-----	111
4.1.1. Popularity of cricket and the nationwide cricket injury prevalence-----	111
4.1.2. Injury-prone body areas due to cricket participation-----	113
4.1.3. The importance of cricket injury surveillance-----	117
4.1.4. The fast bowler and shoulder injuries-----	120
4.1.5. Fast bowling and subacromial space pathology-----	122
4.1.6. Rotator cuff muscle strength and shoulder injury-----	123
4.1.7. Pathomechanism leading to chronic shoulder pain-----	125
4.1.8. Three strategies for reducing fast bowler's shoulder injuries-----	128
4.1.9. Role of Indian clubbells in strengthening the rotator cuff muscles and preventing shoulder injuries-----	129

5. Summary and conclusion:

5.1. Application strategies for fast bowler's shoulder injury prevention-----	133
5.2. Recommendations for musculoskeletal shoulder screening-----	134
5.3. Limitations of the thesis-----	136
5.4. Summary of key findings-----	138
5.5. Future research directions-----	139
5.6. Conclusive summary-----	139
References-----	141

Appendix A; Ethics approval, consent form, information sheet and survey questionnaire (Study 3)

Appendix B; Ethics approval, consent form, information sheet and survey questionnaire (Study 4)

Appendix C; Ethics approval, consent form, information sheet and injury questionnaire (Study 5)

Appendix D; Indian clubbell shoulder strengthening exercise programme (Study 5)

List of tables

Table 2.1: The van Mechelen's model for sports injury surveillance. -----	9
Table 2.2: Published incidence and prevalence of shoulder injuries since the year 2000. ----	15
Table 2.3: Rotator cuff actions and functions. -----	22
Table 2.4: Cricket players shoulder rotational ROM differences. -----	35
Table 3.1: Age-standardised cricket-related injury incidence per 10,000 people-years. -----	47
Table 3.2: Cricket-related injury prevalence by body area. -----	48
Table 3.3: Cricket-related injury type by body area. -----	49
Table 3.4: Cricket-related injury diagnosis by body area. -----	50
Table 3.5: Profiles of players competing in the 2015 ICC Cricket World Cup. -----	63
Table 3.6: Injury prevalence by playing position. -----	64
Table 3.7: Injured body parts by playing position. -----	64
Table 3.8: Overall matches missed per body part. -----	65
Table 3.9: Injury prevalence by activity. -----	65
Table 3.10: Comparison of the injuries between 2011 and 2015 CWC. -----	66
Table 3.11: Anthropometric data (mean \pm range) n= 35. -----	77
Table 3.12: Injury prevalence and missed days by body area. -----	78
Table 3.13: Activity during acute injury onset. -----	79
Table 3.14: Medical diagnoses for the reported injuries. -----	80
Table 3.15: Participant descriptive data (mean \pm range). -----	94
Table 3.16: Differences of ROM, IMS and posterior shoulder tightness (mean \pm range). ----	94
Table 3.17: Participant characteristics. -----	105
Table 3.18: Changes to the range of motion, isometric muscle strength and posterior shoulder tightness throughout the six week period. -----	106

List of figures

Figure 3.1: Cricket-related injury prevalence of the most injury-prone body areas during the 12 years. ----- 51

Figure 3.2: Shoulder injury pathomechanism and suggestions for prevention. -----131

List of abbreviations and nomenclature

AC - Acromioclavicular joint

ACC - Accident Compensation Corporation

CM - centimetres

CWC - Cricket world cup

D - Dominant

ER - External rotation

EMG - Electromyography

FIFA - Fédération Internationale de Football Association (International Federation of association football)

GH - Glenohumeral joint

GIRD - Glenohumeral internal rotation deficit

HEC - Human ethics committee

HHD - Handheld dynamometer

ICB - Indian clubbells

ICC - International cricket council

ICC - Intraclass correlation coefficient

IMS - Isometric muscle strength

IR - Internal rotation

IRD - Internal rotation difference

Kg - Kilograms

LLC - Limited Liability Company

M - Meters

MRI - Magnetic resonance imaging

ND - Non-dominant

N.m - Newton metres

NZ - New Zealand

NZC - New Zealand Cricket

ROM - Range of motion

RMS - Root mean square

SA - South Africa

SC - Sternoclavicular joint

SCT - Scapulothoracic joint

SITS - Supraspinatus, Infraspinatus, Teres minor, Subscapularis

T20 - Twenty-20 short-form cricket

USA - United States of America

CHAPTER ONE

Introduction

1.1 Background

Elite cricket was traditionally only played over multiple days but has now evolved into shorter game formats including 50 over (one-day) and twenty-over innings matches. With the introduction of limited-over tournaments by international cricket boards, elite players frequently travel and play international cricket throughout the year (Soomro et al., 2018, Khondker and Robertson, 2018). Private club ownership and associated corporate sponsors have expanded the opportunities for elite players to obtain playing contracts for international cricket clubs (Khondker and Robertson, 2018).

The development of the sport over the past decade requires elite cricketers to be available for selection throughout the year (Soomro et al., 2018). Subsequently, to be selected for a tournament, players need to maintain an optimal fitness level throughout the year (Khondker and Robertson, 2018). The necessity to play multiple cricket formats and attend various fitness sessions throughout the year has increased the physical workload of the contemporary first-class player in comparison to the years gone by (Hulin et al., 2014b). The decreased number of rest days per week in tightly scheduled tournaments results in less between-game recovery (Hulin et al., 2014b). It is theorised that shorter recovery durations combined with increased playing and training workloads might eventually deteriorate the shoulder joint's anatomical structures which are repeatedly being stressed (Hulin et al., 2014b). A wealth of information is available on elite cricket injuries, but much less is known about the nationwide cricket-related injury prevalence of the general public participating in cricket.

The rising prominence of the internet and streaming media services has enabled international cricket to be enjoyed by a greater global audience. The success of shorter cricket formats has enabled many elite players to sign highly paid playing contracts, and these factors may have indirectly led to an increase in the general public playing cricket with the hopes of playing at the elite level (Ians, 2020). With increased cricket participation, injury surveillance amongst the general population becomes more important. There is also a possibility that recreational cricketers may skip thorough warmup activities and may not engage in planned adequate conditioning sessions, and due to time restrictions, many also prefer to instead focus on just playing cricket during the weekends. This scenario potentially exposes recreational cricketers to more sudden loading and a heightened likelihood for acute injuries. For epidemiological reasons, injury type, onset, prevalence rate and injury mechanism could differ between elite

cricketers and the general public playing cricket. Hence, to better understand of cricketing injury risk, nationwide injury surveillance among the general public participating in cricket is highly recommended to quantify, identify and analyse nationwide cricket injury prevalence.

Longer-term cricket injury surveillance throughout the pre and playing season is the preferred methodological approach to systematically identify the most injury-prone positions and body parts and take targeted preventive measures. Past cricket injury surveillance studies amongst elite cricketers have identified that fast bowlers experience the highest injury prevalence (Orchard et al., 2002). Fast bowler's predisposition to injury has been identified as multifactorial, with factors such as bowling style, landing biomechanics, increased workload, training mal-adaptations, recurrent injuries and joint anatomy all having been implicated (Arora et al., 2015, Ferdinands et al., 2010, Kountouris, 2017, Olivier et al., 2016b, Orchard et al., 2017, Sharma et al., 2012). With fast bowlers, the lower back, ankle/foot and thigh have been acknowledged as the most injury-prone body areas with only a few studies highlighting the high prevalence of injuries to the shoulder area (Ranson and Gregory, 2007).

Cricket injury surveillance results have identified that the upper limb sustains 20-26% of all injuries (Stretch, 2018). In the shoulder, the glenohumeral joint accounts for up to 22% injuries due to cricket fielding and bowling (Stretch, 2018). The rotator cuff muscles act as dynamic stabilisers, the ligaments and joint capsule act as the static stabilisers for the glenohumeral (GH) joint (Alpert et al., 2000). Asymmetry in the strength of the shoulder rotators has been proposed as a predisposing factor for shoulder injuries (Mabasa et al., 2002). A decrease in the GH joint's rotational range of motion (ROM) has been observed among fast bowlers with shoulder injuries (Stuelcken et al., 2007, Aginsky et al., 2004). Therefore, when questioning aetiology of shoulder pain, it is essential to assess the ROM and muscle strength.

1.2 Statement of the problem

To better understand cricket injuries, it is essential to undertake a nationwide survey of injuries occurring at all levels of cricket. This survey must quantify injuries which occur in elite and general public cricket participation. Globally, there is no published cricket specific injury surveillance report on a nationwide population. The last published injury surveillance report of elite New Zealand cricketers was in 2008, concluded that elite NZ fast bowlers are the most injury-prone (Frost and Chalmers, 2014). The 2008 study also highlighted that the shoulder was one of the most injury-prone body parts, but there is no clear understanding of shoulder injury aetiology specific to cricket bowling.

Concerning the shoulder area, the glenohumeral joint rotates during bowling and fielding-throwing. Glenohumeral rotation is produced by the contraction of the rotator cuff muscles. The rotator cuff muscles also resist humeral translation during the same movement and act as the joint's dynamic stabilisers. It has been postulated that long term repetitive rotational movements with short recovery periods may cause anatomical structural changes to the joint's soft tissues and affect stability. So, assessing muscle strength asymmetries of the shoulder-rotators and rotational range of motion is recommended (Whiteley and Ocegüera, 2016). However, very few studies have explored muscle strength asymmetries of the shoulder-rotators and rotational range of motion specific to cricket fast bowlers.

Humeral translation has been associated with overuse-related shoulder conditions such as subacromial impingement, bursitis and rotator cuff inflammation (Lopes et al., 2015). Strengthening the shoulder rotators has been recommended to increase glenohumeral joint stability and to avoid humeral translation (Lopes et al., 2015). However, the efficacy of such strengthening programmes specifically for cricketers' shoulders has not yet been investigated.

1.3 Thesis objectives

1. To determine how many cricket-related injuries are occurring among New Zealand's general population (Study 1).
2. To determine what elite cricketers are doing at the time of injury onset (Study 2).
3. To determine where and how elite fast bowlers are getting injured (Study 3).
4. To determine differences in the shoulder joint's range of motion and muscle strength between injured and uninjured fast bowlers (Study 4).
5. To investigate the effects of an exercise programme on rotator cuff muscle strength and shoulder rotational range of motion (Study 5).

1.4 Significance of the research

Currently, there is no nationwide cricket-related injury surveillance study on New Zealand's general population. The results of this thesis's first study will provide information on the most injury-prone age group and body area, injury type and injury cause from all of New Zealand's resident male population. This will include everyone from recreational cricketers to primary school cricketers to elite national level cricketers. The findings could be used by coaches and physiotherapists across the country to create and implement targeted cricket injury prevention programmes.

Despite the importance of cricket injury surveillance being widely acknowledged, the official implementation of injury surveillance still lacks at major international tournaments. There are no published injury surveillance reports of the 2015 International Cricket Council (ICC) Cricket World Cup. The findings of this thesis's second study will be the only recorded injury report from the 2015 ICC cricket world cup, and this media-based injury surveillance will provide an overview of the injury prevalence during the 2015 cricket world cup.

The last published injury surveillance study amongst elite New Zealand cricketers was over a decade ago in 2008. As it is widely acknowledged that fast bowling is the most injury-prone position, study 3 was focussed solely on this position. While lumbar and thigh injuries have been well investigated among cricket players, there is still a paucity of research on shoulder injuries. Thus the findings of study 3 will provide insight into the current injury prevalence of New Zealand's elite fast bowlers, and will also provide a detailed description of their specific injury diagnoses.

Deficits in shoulder muscle strength and range of motion have been well documented amongst overhead throwing sports athletes experiencing shoulder pain. In cricket, there have been only two studies which have reported these deficits. Therefore, the findings of study 4 will report differences observed between fast bowlers with shoulder injuries and healthy fast bowlers. Based on these findings, strengthening programmes for injury prevention of the shoulders could be developed. To date, there is no evidence-based rotator cuff strength programme specific to cricket fast bowlers. The fifth study of this thesis will establish the effectiveness of a six-week Indian clubbell exercise programme for increasing the shoulder's rotational range of motion and rotator cuff muscle strength. The exercise programme used in

study 5 could be used by cricket physiotherapists and coaches as part of a shoulder injury prevention programme.

CHAPTER TWO

Review of literature

2.1 Introduction

This literature review provides an introduction to cricket and will discuss the various aspects of cricket injuries. It will explore previous injury surveillance research to understand the aetiology of cricket-related injuries. This review will also investigate the pathomechanisms of cricket-related shoulder injuries and revise evidence-based injury prevention measures.

Cricket was predominantly played as a summer sport, but the seasonal game also has transitioned into a year-long season for elite level players (Soomro et al., 2018). Historically cricket was played as a multiday test format, but currently, the game has also transitioned into shorter limited over game formats (Soomro et al., 2018). With the commercialisation of limited over cricket formats and the privatisation of cricket clubs, elite cricketers can more easily play cricket throughout the year at home and abroad. With the rise of internet streaming services, internationally played cricket matches are regularly being viewed by nationwide populations. These contemporary changes may often increase a general population's cricket participation numbers, which in turn increases the number of sports injuries. Measurement of a sport's injury prevalence by undertaking quality injury surveillance allows targeted preventative measures to be introduced.

Sports injury surveillance

The sports injury prevention model proposed by van Mechelen in 1992 has been adopted by several sports injury prevention programmes and stems from the public health model of epidemiological studies (van Mechelen et al., 1992). To understand the extent of an illness in a specific population or area, a methodological approach of the affected population or area will provide insight into the prevalence of the illness, cause of the illness and help formulate a countermeasure to control it. Based on this approach, van Mechelen proposed four stages as shown in Table 2.1

Table 2.1. The van Mechelen's model for sports injury surveillance

Stage 1: Quantification of the sports injury problem
Stage 2: Identification of the injury aetiology
Stage 3: Introduction of preventive measures to reduce the injury risk
Stage 4: Evaluation of the introduced preventive measures by repeating the first stage

The van Mechelen's sports injury prevention model, aids in assessing the effectiveness of injury prevention measures. To quantify the extent of sports injury prevalence, effective injury surveillance must be implemented. Effective injury surveillance requires compliance from players, coaches, management and support staff. Identification of more injury-prone positions and body parts involves regular monitoring and recording of injury data. Injury surveillance can be done either prospectively or retrospectively. Retrospective injury surveillance has limitations such as invalidated surveys, recall bias, injury definition discrepancy and lack of exposure information. Prospective injury surveillance requires rigid monitoring, team compliance, accurate logging of exposure and injury data. Outcome data from injury surveillance reports will help identify risk factors, aetiology and pathomechanism of injuries. Identification of the most injury-prone positions, body parts and causative factors helps to develop specifically targeted injury prevention programmes (Soligard et al., 2015). The importance of injury surveillance in preventing cricket injuries is widely accepted.

Several studies have been conducted across different cricket playing nations to quantify cricketing injuries. The following sections will review past injury surveillance studies and highlight the importance of the "injury definition" adopted in those studies.

2.2 Review of cricket injury surveillance

Cricket is a global sport, and a recent International Cricket Council (ICC Media releases, Live Cricket Scores & News International Cricket Council, 2019) report states that there were 104 registered member nations with 12 nations as full members and 92 nations as associate members. From elite international cricket to county, school and club cricket the game is played by both men and women across the globe. So, it is essential to monitor injury prevalence across all levels of the sport and to implement appropriate preventative strategies. Implementation of various injury surveillance strategies has been carried out by different cricket boards across the world.

Injury definitions in cricket

The definition of an injury plays a crucial role in estimating the prevalence of a cricket injury while conducting injury surveillance. One of the earliest injury surveillances in cricket was undertaken among provincial South African cricket teams from 1998 to 2001 (Stretch, 2003).

In this study, the adopted injury definition was of time-loss “*An injury was defined as any pain that prevented the player from completing that particular match, practice, or training session and caused the player to seek medical attention*”. Following the methods adopted in the study, cricket injury surveillance was undertaken across different countries with the same time-loss definition. The limitation for recording time-loss injuries alone is that, only when an injury is severe enough for the player to miss a match will it be recorded as an injury.

In 2002, a four-year injury surveillance report amongst Australian state and national teams were undertaken using the (Orchard et al., 2002), injury definition “*any player who is unavailable for selection for his specific position*”. This injury definition was modified to record the number of players continuing to play cricket but refraining from playing in their speciality position. For example, a speciality bowler experiencing musculoskeletal pain or discomfort may continue to play as a mid-order batsman or fielder. The advantage of this modified injury definition was that they were able to identify injury prevalence based on the playing position, but the limitation was that this injury definition still recorded only time-loss injuries

However, in another study conducted amongst 70 English county cricketers’ (Gregory et al., 2004b) injuries specific to only bowlers were recorded. Unlike previous studies, a non-time loss injury definition was used, and they were able to collect data on pain experienced by the bowlers even during cricket training. In this study, the researchers highlighted that the bowlers continued to play and train with pain but reduced the intensity of their bowling. This was the first study where injury was recorded subjectively regardless of matches missed.

In 2005, a consensus on the methods for conducting international cricket injury surveillance was formalised between researchers from six major cricket playing nations. The definitions for cricket injury, injury recovery, recurrence, seasons, teams and surveillance cohort was agreed. The injury definition adopted was based on a time-loss injury where “*a player is not fully available for selection for a major match or during a match causes a player to be unable to bat, bowl or keep wicket when required*” (Newman et al., 2005). Adopting a time-loss injury definition may quantify injury prevalence, but it may be too late to implement preventive measures because the players are already injured and have missed a match.

In order to reduce the risk of an injury, if the presence of pain or discomfort is recorded ahead of time, then preventive measures could be implemented. This was particularly highlighted in a 2005 study among elite cricketers (Ranson and Gregory, 2007). In this study, the researchers suggested that there is a need to modify the injury definition especially to quantify shoulder injury prevalence, as shoulder injuries did not cause the bowlers to miss matches and players continued to play with the pain. The shoulder injury was defined as “*any shoulder pain, weakness or instability that compromised cricket performance or training or affected their daily living activities*”.

From the literature review, it is also understood that if injury surveillance is collected only from time-loss medical reports, then mild pain or musculoskeletal discomfort will not be recorded as the player may not have sought medical attention and may not have missed a match. Hence, it is suggested that modification of injury definition is required and the new injury definition should record any mild onset of pain, even if it is not severe enough to miss matches or trainings and it has to be subjectively reported by the player. If injury surveillance is subjectively collected, players can also indicate the pain severity so that the onset of a chronic overuse injury could be monitored.

Injury prevalence and incidence in cricket

Injuries in cricket could be either acute due to sudden onset or chronic due to gradual onset. One of the first studies to investigate the nature of cricket injuries was conducted between the years 1985-1995 amongst 54 professional English cricketers. In this study, only acute injuries were reported with no mention of injuries due to overuse. It was reported that 57.4 acute injuries occurred per 1000 days of cricket played. This study recommended a need to develop a systematic method to collect cricket injury data. Following this a three-year injury surveillance with 11 provincial South African cricket teams from 1998 to 2001 (Stretch, 2003) revealed that acute injuries (64.8%) were higher than chronic injuries (22.5%) and acute on chronic injuries (22.8%), the study also suggested that between playing positions fast bowlers are likely to be injured due to overuse injuries.

In comparison to the early cricket injury surveillance studies, a longitudinal study from the years 1998-2001 conducted amongst Australian first-class cricketers (Orchard et al., 2002)

explored injury incidence and prevalence. In this study comparison of match injury incidence between different game formats were reported. The study revealed that one-day international matches (44.7 injuries/10000 player hours) played at home grounds caused the highest injury incidence while test matches (17.3 injuries/ 10000 player hours) played away from home had the lowest injury incidence. This study paved the way for reporting injuries as incidence rates so that the severity of the sustained injuries could be estimated.

The calculation of injury incidence between matches played at home and away was also highlighted in a study amongst first-class West Indian cricketers (Mansingh et al., 2006). In the study, it was revealed that matches played away (61.1 injuries/10000 player-hours) from home had a higher injury incidence rate than matches played at home (31.1 injuries/10000 player-hours) in both one-day and test matches. The researchers suggested that the unavailability of a medical doctor with the team while touring may have contributed to more injuries and also the training workload needs monitoring.

In addition to reporting incidence and prevalence, further studies have tried to identify the circumstances of an injury. In 2009 a ten-year prospective study (Frost and Chalmers, 2014) amongst New Zealand elite cricketers reported that majority of injuries occurred while playing matches (79.5%) in comparison to cricket practice (20.5%). All the injury surveillance studies have reported varying injury prevalence rates and used different methods. In order to bring uniformity in the methods of injury surveillance in cricket, an international consensus (Newman et al., 2005) on cricket injury surveillance was agreed and published in 2005. The consensus defined injury definitions and injury rate calculation methods. In the consensus, all injuries were based on time-loss, and injury rates were recommended to be presented as prevalence rates only if exposure hours could not be estimated; otherwise, all injury rates were to be presented as incidence rates.

Injury-prone body areas in cricket

Identification of injury-prone body areas is essential to provide targeted injury prevention programmes; the lumbar (88) region has been identified to be the most injury-prone area for over two decades (Stretch, 2003). While early injury surveillance studies reported as whole body areas, further research classified body areas to more specific body parts. A four-year cricket injury surveillance study conducted amongst Australian elite cricketers (Orchard et al., 2002), was able to report specific injuries such as hamstring strains (11 injuries), wrist (11 injuries) and abdominal side-strains (9 injuries).

Understanding the nature of the injuries is also essential for injury prevention. Lumbar injuries are mostly due to non-contact and involve the lumbar muscles and intervertebral discs. Amongst South African provincial age-group cricketers, it was found that lower back muscle strains (78 injuries) were higher than stress fractures (33 injuries) (Stretch, 2003). This finding is also confirmed by another study where, 55 lumbar injuries were recorded during a six-year observational study amongst Australian first-class cricketers, out of which 41 injuries were soft tissue related, and only 14 were classified as lumbar fractures (Orchard et al., 2002).

Along with lumbar injuries, the thigh area is also frequently injured and has been reported to have had an increase in injury rates especially after the prominence of T20 cricket (Orchard et al., 2017). Previous injury has been cited to increase the risk of a recurrence (Orchard et al., 2015). Bowling workloads with low rest days have been postulated to contribute to thigh injuries (Gabbett, 2016). A 7-year study amongst 248 New Zealand male cricketers revealed that the most frequently injured body areas were the thigh (17.1%), followed by the lower back (14.2%) (Frost and Chalmers, 2014). Between the playing positions, the fast bowler is required to run further, and faster; hence injury surveillance studies reveal thigh injuries have their highest prevalence amongst fast bowlers (Orchard et al., 2017). Over the years, very few studies have reported on shoulder injury prevalence. Elite South African cricketers were monitored over three playing seasons for acute and overuse injuries, at the end of the study 812 injuries were reported amongst 436 cricketers with 41 injuries in the glenohumeral area (Stretch, 2003). Injuries to the shoulder have been reported to mostly occur amongst fast bowlers who bowl more than the recommended limit

Table 2.2. Published incidence and prevalence of shoulder injuries since the year 2000

Author	Surveillance cohort	Duration of study	The incidence of a reported shoulder injury	Prevalence of reported shoulder injury
Ranson et al., 2013	76 players from 5 competing international teams	ICC cricket world cup 2011	0.2%	0.1%
Frost and Chalmers, 2014	248 elite New Zealand male cricketers	2002-2008	6.3% incidence	Not reported
Dhillon et al., 2012	95 players of Punjab Ranji trophy team and under 19 teams of Punjab cricket association	November 2008 - October 2009 - One playing season and one offseason	16.8% experience upper limb injuries 5 bowling injuries 2 fast bowling injuries 2 shoulder injuries	Not reported
Ranson and Gregory, 2007	158 English first-class XI county cricketers	2005 county season	23% experienced shoulder injuries	1.7%
Stuelcken et al., 2007	26 elite Australian female fast bowlers	2006	12 fast bowlers	46%
Orchard et al., 2006	Australian male cricketers at state and national levels	Ten years	For all playing positions mean seasonal shoulder injury incidence of 1.1	For all playing positions mean seasonal shoulder injury prevalence of 0.75
Mansingh et al., 2006	West Indies National team and first-class domestic teams	June 2003 to December 2004	Shoulder injury: 0.02	Not reported
Stretch, 2003	11 provincial and national South African teams	Three seasons	Glenohumeral joint: 21.7%	Not reported
Gregory et al., 2002	113 young cricket bowlers from three English county cricket centres of excellence	Six months composed of 3 months preseason and three months playing season in 1998	14 shoulder injuries Fast bowler incidence: 0.007 Spin bowler incidence: 0.055	Not reported
Orchard et al., 2002	Australian male cricketers at state and national levels	1995-1996 and the 2000-2001 season	6% bowling shoulder tendon injuries	Shoulder tendon injury prevalence: Fast bowler: 0.9 %, Spin bowler: 1.1 %
Leary and White, 2000	54 English first XI county cricketers	1985 – 1995	Upper limb 29.4% of which 7.1 % associated with the shoulder.	Not reported

(Gregory et al., 2004a). Among other elite cricket studies, shoulder injury prevalence has been reported to range from 0.75% to 1.7% per year (Orchard et al., 2006, Ranson et al., 2013, Frost and Chalmers, 2014). Shoulder injuries may be either acute or overuse, in cricket acute shoulder injuries could occur due to falling on the ground while fielding or due to collision with a player or ball, but the chances for shoulder pain to develop over time gradually is high because of the repetitive bowling and fielding throwing (Saw et al., 2011). This understanding of the shoulder injury mechanism is supported by a study amongst English cricketers where it was found that 69% of players continued to play with shoulder pain and 75% of shoulder injuries always occurred on the dominant throwing/bowling arm (Ranson and Gregory, 2007). To further review cricket injuries, it is critical to focus on highly injury-prone playing positions so that injury aetiology could be linked to the activity leading to injury.

Injury-prone playing positions

Fast bowlers injury predisposition has been reported amongst several injury surveillance studies (Stretch, 2003). Over three playing seasons, it was reported that 41.3% of all injuries occurred while bowling amongst South African elite cricketers. This early injury surveillance study was the first to identify the injury predisposition for the fast bowling position. While it was unclear why the fast bowler was so injury-prone, further research was directed into exploring the cause. In 2002, a four-year injury surveillance report amongst Australian state and national team cricketers concluded that high workload and bowling second (after batting) predisposed the bowlers to increased injury risk (Orchard et al., 2002). In the same study, it was also identified that fast bowlers who bowled five days/week and also bowled more than 20 overs/week, especially the week before a major match had the highest risk for injury. In this study, they also identified that 6% of the cricketers experienced shoulder tendon injuries, as shown in Table 2.2. From this study, it is understood that there is a high predisposition for injuries for the fast bowler. It also implies that the bowling workload needs to be monitored as it is a major risk factor for injury.

To further understand the fast bowler's injury risk, six months of bowling workload data from 70 English county cricketers' was analysed (Gregory et al., 2004b). In this study, the average cricketer's age was only 15.3 years, and only injuries specific to bowling were

recorded. Unlike previous studies, non-time loss injuries and pain during cricket training were also recorded. The bowling related pain severity was classified as

Grade 1= pain following bowling

Grade 2 = pain while bowling

Grade 3 = pain impairs bowling

Grade 4 = pain preventing bowling

The results showed a 32.8% injury incidence of grade 3 and 4 injuries per 100 fast bowlers. Interestingly the knee (11.4%) and ankle (8.6%) had the highest injury incidence amongst the cohort. The study concluded that 12% of fast bowlers exceeded the English cricket board's bowling workload for 15-year-old cricketers. Also, bowlers who bowled more than 1000 balls during a playing season had a higher injury incidence in comparison to those who bowled less than 1000 balls during the playing season. Based on the study findings, it is understood that logging of bowling workload helps stay within recommended bowling workload guidelines and will eventually help in reducing injuries of young cricket fast bowlers.

The high bowling workload injury risk finding was further confirmed by a study amongst 44 junior male Australian fast bowlers during the 2002-2003 playing season (Dennis et al., 2005). In this study during an entire season, the pre and post-injury bowling workload of the injured bowlers were analysed. Amongst the 44 bowlers in the study, 25% reported at least one overuse injury. On analysis of bowling logs, it was revealed that junior bowlers exceeded 8% of the match deliveries per day in comparison to exceeding 42% of training deliveries per training day. The injured players had significantly bowled more frequently than the uninjured. Bowlers bowling more than three days per week and fifty deliveries per day had a higher injury risk. From this study, it is understood higher bowling frequency per week predisposes cricketers to injury. Also, rest days between bowling-days are essential for the fast bowler to recover and limit injury occurrence.

To answer the question of injury predisposition for the cricket fast bowler, 46 South African junior fast bowlers were assessed for their posture and physical fitness during the preseason. They were given bowling logs to monitor the weekly bowling workload (Davies et al., 2008).

For this study, all reporting of pain was recorded even if the player did not miss a match or training. Only 15% of the fast bowlers remained uninjured during the eight months. The bowlers mostly injured their knees (41%), lower back (37%) and shoulders (16%). It was found that 43% fast bowlers displayed knee hyperextension, 39% had lumbar lordosis and 30% displayed scapular winging. They also found that the bowlers with higher bowling workload had a strong relationship with a higher number of weeks incapacitated due to injury. Although this study was the first to report a high prevalence of shoulder injuries, the association between scapular winging and the shoulder injury prevalence was not made. The diagnoses of those shoulder injuries were also not reported. Another difference in this study compared to previous injury surveillance studies was the injury definition. This study recorded any reported pain regardless of time-loss, so players who continue to play with the presence of pain were also monitored.

These discrepancies in injury prevalence rates across the cricket injury surveillance studies imply that quantification of injury prevalence relies heavily on injury definition. As the intensity of pain for overuse injuries gradually increases over a period of time, players often ignore the mild onset of pain and will continue to play, in order to be available for selection. The downside to this is that, if the pain is ignored at an early stage, it will further aggravate the tissue and can develop into a chronic condition. This will eventually cause long term time-loss for the player. Therefore, recording of non-time loss injuries is vital to monitor players as it helps initiate preventative measures at an early stage.

In a study conducted during the 2005 English cricket season (Ranson and Gregory, 2007). The cricketers were asked to report all pain, even if they did not miss training or matches amongst the 158 players, 36 reported shoulder injury during the playing season. Twenty-five (69%) of the 36 injured players did not miss any matches during the season. By playing position fast bowlers (21.4%) and batsmen (33.3%) reported the highest percentage of a shoulder injury. Also 29 of the 36 (80.5%) injured players reported that their shoulder injury never caused them to miss or drop the ball during fielding. Twenty-one injured players also reported that they chose to field within the circle to avoid any forceful throws as they noticed a power reduction if they had to throw from the outfield. The injured bowlers also reported that they chose to reduce the number of overs and balls bowled during matches and training. This finding provides evidence that shoulder injuries among fast bowlers might not cause them to miss matches, but it will impair their performance. Fifty per cent of the injured

bowlers in the study also reported that they reduced the number of balls bowled in training and 35% reduced the number of overs bowled in matches. Speed of the delivery was affected in 45% of the bowlers due to shoulder pain. As fast bowlers arguably bowl the most crucial overs in any cricket format, they need to bowl each delivery optimally.

Furthermore, a study among elite New Zealand cricketers highlighted that 48.7% of all injuries were sustained during bowling (Frost and Chalmers, 2014). During the eight-year study period, fast bowlers (18.7%) experienced the highest injury prevalence in comparison to all playing positions. A time-loss definition was used in the study. A 6.3% shoulder injury prevalence was reported amongst all playing positions with an injury specific diagnosis of 11 shoulder muscle strains. This study described overall injury prevalence. However, if the specific player position and specific body part injuries need addressing, injury surveillance needs to be more specifically targeted.

General cricket injury surveillance studies do not provide that much information on shoulder injury diagnoses and the anatomical structures affected due to the injury. Obtaining diagnostic information might help ascertain the nature of shoulder injuries. It may also help identify the affected tissues. The diagnostic information may also provide insight into the structural adaptations occurring in those tissues due to repetitive cricket bowling and throwing. Obtaining prospective diagnostic information for cricket shoulder injuries requires strict compliance and timely reporting from medical support staff. It can also be time-consuming waiting for overuse injuries to occur. Alternatively, if retrospective data is collected, it can provide insight into past injuries, especially chronic injuries. Retrospective injury surveillance could also be used to study the timeline on shoulder injury onset from mild pain to pain, restricting bowling action.

A study in 2010, conducted amongst 95 state-level Indian cricketers (Dhillon et al., 2012), described the upper limb injury diagnoses of the fast bowlers, as shown in Table 2.2. The study reported that acute injuries on the fingers were mostly caused due to fielding. The study also suggested that bowling may have caused repetitive strain and chronic inflammation to the supraspinatus tendon (Dhillon et al., 2012). The supraspinatus muscle (Boettcher et al., 2010) is the primary shoulder abductor, and it has to elicit force to abduct the bowling arm every time a fast bowler bowls a delivery. So it could be that frequent bowling will cause repetitive strain on the supraspinatus muscle.

Based on the injury surveillance literature review, it is understood that fast bowling is the most injury-prone position in cricket. It is also revealed through these years of injury surveillance reports that the shoulder is one of the most injured body parts for a fast bowler, but the prevalence rates vary depending on the adopted injury definition. Previous research also indicates that higher bowling throwing workload and low rest periods may be an important factor contributing to shoulder injuries (Olivier et al., 2016b); also most shoulder injuries are overuse in nature. Very few studies have been able to describe the anatomical structures affected in the shoulder region due to the repetitive use. Also, if injury aetiology of a specific playing position or specific body part needs to be explored, it is recommended that injury surveillance is focussed on that position or body part because general injury surveillance does not provide detailed information, specific to a body part or playing position.

From the literature review, it is also understood that subjective reporting of pain collected directly from players would capture descriptive information of chronic overuse injuries. Because, if the pain is mild, the player may not seek early medical attention for fear of not getting selected for a match. Players may continue to participate, ignoring the pain. Overuse pain usually starts with a mild onset of pain and gradually increases in severity. However, the early mild pain is also an indication of some initial pathological change. So, ignoring the pain may affect the player at a later stage. If injury surveillance is collected only from medical reports, then such mild pain conditions will not be recorded as the player has not sought medical attention. Hence, it is suggested that any mild onset of pain, even if it is not severe enough to miss matches or trainings has to be subjectively reported by the player. If injury surveillance is subjectively collected, players can also indicate the pain severity so that the onset of a chronic overuse injury could be monitored. In order to further understand the fast bowler's shoulder injuries, the anatomy of the shoulder must be studied.

2.3 Anatomy of the shoulder joint

Overhead arm movement is a complex movement involving several joints in the shoulder. The shoulder consists of sternoclavicular (SC), acromioclavicular (AC) and, glenohumeral (GH) joints, as well as the scapula thoracic (SCT) joint articulation (Halder et al., 2000). The SC joint is a fibrocartilaginous saddle-type joint formed by the articulation between the proximal end of the clavicle and manubrium sterni (Halder et al., 2000). During bowling and throwing action in cricket, the SC joint permits protraction, retraction, elevation, depression

and rotation. The joint is stabilised by the sternoclavicular ligament, costoclavicular ligament and interclavicular ligament. The SC joint is rarely involved in any cricket injuries with sporadic reports of acute injury while fielding-diving. The AC joint is a gliding synovial joint formed by the articulation of the acromion portion of the scapula and clavicle. The joint is stabilised by acromioclavicular ligament, coracoacromial ligament, and coracoclavicular ligament.

The acromion process of the scapula functions as a pivot point for any shoulder rotational movements. The shape of the acromion is either flat, curved or hooked (Cuéllar et al., 2017, Brukner, 2012). Cricketers with curved or hooked acromion have a higher injury predisposition to impingement related shoulder pain. The space below the acromion process is called the subacromial space and shoulder radiographs suggest that normal subacromial space should be 9-10mm and, any reduction in the space leading to impingement of its soft tissues and subsequent pain in the shoulder (Cowderoy et al., 2009). Beneath the acromion is a synovial cavity called the subacromial bursa; it serves to reduce friction between the acromion and the humeral head during any abduction movement of the shoulder. The AC joint is the least mobile joint in the shoulder, although it is the most susceptible to dislocation (Brukner, 2012). The common mechanism of AC joint dislocation is falling on an outstretched hand, also referred to as FOOSH injury. AC joint dislocation could occur during diving-falls while running between the wickets or while fielding-diving.

The GH joint is a synovial ball-and-socket joint connecting the upper arm to the trunk. Articulation of the humeral head with the scapular glenoid cavity forms this joint (Halder et al., 2000). The glenoid cavity is lined by a ring of cartilaginous fibre called the glenoid labrum which increases its concavity. The space between the glenoid cavity and the humeral head is called the glenohumeral space, and the normal glenohumeral space is 4-5mm (Brukner, 2012). Any decrease or increase in the space is associated with shoulder pathology (Page, 2011). The GH joint has a high degree of mobility due to the lack of close articular surfaces. This regional anatomy of the shoulder joint offers very little protection against trauma or violent shoulder depression (Cuéllar et al., 2017). The humeral head presents as a large lever within the relatively small glenoid cavity allowing the upper arm a greater degree of mobility, making it susceptible to injuries. The stability of the shoulder joint relies on its dynamic and static stabilisers.

The dynamic stabilisers are formed by Supraspinatus, Infraspinatus, Teres Minor and Subscapularis (SITS) muscles, collectively referred to as the rotator cuff (DeFranco and Cole, 2009). The supraspinatus muscle arises from the supraspinatus fossa of the scapula. It passes into the subacromial space below the acromion and inserts into the humeral greater tubercle. It functions to resist inferior translation of the humeral head and abducts and rotates it internally (DeFranco and Cole, 2009). The infraspinatus arises from the infraspinatus fossa of the scapula and also attaches to the humeral greater tubercle. The infraspinatus functions to resist posterior humeral head translation and externally rotates the humeral head. The supraspinatus and infraspinatus are susceptible to injury due to their position in the subacromial space and large insertion space on the humeral head (DeFranco and Cole, 2009). The teres minor originates from the scapular lateral border and inserts into the GH joint capsule and humeral greater tubercle. The teres minor functions to resist anterior humeral translation and externally rotates it. The strongest of the four rotator cuff muscles are the subscapularis, originating from the subscapular fossa and inserting into the humeral lesser tubercle. It functions as the primary agonist for humeral internal rotation and resists its anterior translation (Sano et al., 2013). The functions of the dynamic stabilisers are summarised below:

Table 2.3. Rotator cuff actions and functions

Muscle	Action	Function
Supraspinatus	Abduction, Internal rotation	Resists humeral inferior translation
Infraspinatus	External rotation	Provides humeral compression
Teres minor	External rotation	Resists humeral anterior translation
Subscapularis	Internal rotation	Resists humeral posterior translation

The roles of the rotator cuff muscles are to provide compression on the humerus and centre it in the glenoid fossa, thereby maintaining GH joint stability and creating the torque to rotate the joint (Alpert et al., 2000, Tannenbaum and Sekiya, 2011). The static stabilisers of the shoulder joint are the ligaments surrounding it. The glenohumeral ligament's anterior and posterior bands are attached to the glenoid labrum and the glenoid fossa. The glenohumeral ligament resists anterior and posterior translation of the humeral head (Timmons et al., 2012a). When external rotation and abduction occurs at the glenohumeral joint, the glenohumeral ligament rotates anteriorly and provides stability to the joint. The glenoid labrum which lines the glenoid fossa also acts as a static stabiliser for the joint by increasing

the superior-inferior and anterior-posterior diameter of the glenoid fossa. The stability and mobility of the glenohumeral joint rely on the strength of the dynamic and static stabilisers, weakness of the dynamic stabilisers will stress the static stabilisers and affect joint movements (Blume et al., 2015). Shoulder anatomy explains the vulnerability of the joint to injuries and how the complex articulation between clavicle, humerus, scapula and thoracic cage to ensure the smooth glenohumeral rotational movements. In order to create tailored injury prevention strategies for the shoulder, the most commonly reported injuries in the shoulder need to be understood.

2.4 Common cricketing shoulder injuries

Fatigue, overuse, sudden loading, strength deficits and previous injury may all affect the strength of the tissues responsible for shoulder stability and also contribute to the fast bowler's shoulder injuries. Hence, it is essential to examine commonly reported shoulder conditions so that specific preventative strategies can be implemented targeting it.

Shoulder impingement

Shoulder impingement is inflammation of the underlying soft tissues by either the hard bony tissue of the humerus or the scapular acromion (Watts et al., 2017). Impingement related pain is one of the most commonly diagnosed clinical conditions for shoulder pain amongst cricketers. Shoulder impingement is generally categorised as an overuse injury. The majority of the clinical presentations report a mild persisting pain around the acromial region lasting longer than 2-4 weeks (Brukner, 2012). Shoulder impingement is classified as external and internal impingement (Mackenzie et al., 2015).

External impingement could be either primary or secondary impingement (Fu et al., 1991). Primary external impingement is presented as a congenital condition where the inferior aspect of the acromion process is either beaked, curved or hooked. The primary external impingement condition may also present with osteophyte formation in the acromion but is rarely seen among young cricketers. Secondary external impingement is presented with the encroachment of the subacromial space and is commonly presented amongst the younger athletic population complaining of chronic shoulder pain. The secondary external impingement also called subacromial impingement, occurs as a result of the asymmetry of the scapular stabilising muscles. When the strength balance of the scapular stabilisers is affected,

the scapular tilts anteriorly reducing the subacromial space (Mackenzie et al., 2015). In addition to this pectoralis minor tightness also protracts the scapula further reducing the subacromial space.

Repeated large throwing and bowling volume may also weaken the rotator cuff muscles and causes an imbalance between the deltoids (Bell-Jenje and Gray, 2005). This weakening affects the strength of the rotator cuff muscle and lets the humeral head translate anteriorly leading to encroachment of the subacromial space and compression of the rotator cuff tendons (Brukner, 2012). This is a painful overuse-related condition commonly presented by overhead throwing sports athletes. Due to repetitive bowling and throwing, it has been suggested that cricketer's shoulders may be more prone to subacromial impingement than other overuse related shoulder conditions (Bell-Jenje and Gray, 2005). Preventative measures such as rotator cuff and scapular stabilisation exercises (Steuri et al., 2017, Shire et al., 2017) have been reported to reduce subacromial impingement and in turn, reduce the pain.

Internal impingement also referred to as glenoid impingement, is another overuse condition presented amongst overhead throwing sports athletes (Myers et al., 2006a). Pain manifests in the posterior shoulder while the shoulder joint is externally rotated, abducted and extended. Impingement of the supraspinatus and infraspinatus tendons against the glenoid rim occurs while the athlete repeatedly abducts and externally rotates the arm (Brukner, 2012). It is a normal physical occurrence, but due to overuse, it may also present as a pathological condition (McFarland et al., 1999). Reduction of throwing workload and rest is recommended to reduce the inflammation of the tendons. Bowling-throwing workload monitoring and rest could be advocated as a preventative measure.

Rotator cuff tendinopathy

Rotator cuff tendinopathy is an overuse condition commonly associated with overhead throwing athletes with shoulder pain (Sano et al., 2013). The rotator cuff tendons become swollen and weaker with increased vasculature. Although the true pathogenesis of tendinopathy is multifactorial, the exact causative factors are unknown. Amongst athletes, tendinopathy is caused due to repetitive exercise stress on the tendons, which leads to apoptosis, tendon failure and tendon tear (Teyhen et al., 2008). Athletes complain of pain during abduction, and internal rotation range of motion is reduced. Medical management

involving glyceryl trinitrate patches, ultrasound, non-steroidal anti-inflammatory drugs and corticosteroid injections are the most recommended treatment choices (Brukner, 2012). At early stages of tendinopathy, reduced throwing-bowling workload along with rotator cuff muscle strengthening to correct the scapulohumeral rhythm is recommended (Copeland, 1993). Bowling-throwing workload monitoring (Sgroi and Zajac, 2018), rest and rotator cuff strengthening exercises before the onset of pain are recommended as a preventative measure.

Glenoid labrum conditions

The glenoid labrum is a fibrous ring of tissue lining the glenoid cavity, which increases the concavity of the glenoid fossa and provides stability to the glenohumeral joint (Halder et al., 2000). The shoulder capsule and glenohumeral ligaments are fused into the labrum. Hence, any exaggerated injury affecting the ligaments may also affect the labrum. The long head of the biceps brachii muscle also inserts into the superior aspect of the glenoid labrum predisposing the labrum to trauma when the biceps tendon is injured (Wang and Cochrane, 2001). While bowling and throwing, the biceps tendon exerts excessive traction force at the attachment site of the glenoid labrum and detaches the labrum from the glenoid cavity. This condition is referred to as superior labrum anterior to posterior lesion (SLAP) (Morgan et al., 1998). The athlete complains of pain during abduction and internal rotation of the affected arm. SLAP lesions are either acute or chronic (Wilk et al., 2013). In cricket, acute SLAP lesions may occur due to a traumatic fall while cricket-fielding. It could also occur during weight training sessions involving inferior pulling action. Chronic SLAP lesions may be associated with repetitive throwing, and athletes complain of a gradual onset of pain following throwing practise sessions (Seroyer et al., 2009). Surgical management has been reported to produce the best treatment outcomes, and non-operative care is recommended only for minor SLAP lesions amongst adolescent athletes (Brukner, 2012). Chronic labral tears may be prevented by throwing workload monitoring (Shanley and Thigpen, 2013).

Glenohumeral dislocations

Glenohumeral dislocations could occur either anteriorly or posteriorly. Posterior dislocations are less often reported in cricket (Orchard et al., 2006). Anterior dislocation of the glenohumeral joint is a common sports injury (Hasebroock et al., 2019), but its prevalence is also low in cricket. The mechanism of dislocation is when the athlete falls on the ground with the affected arm being abducted and externally rotated (Murray et al., 2013). Most anterior

dislocations are associated with tissue damage to the anterior aspect of the glenoid labrum. However, the only instance where acute shoulder dislocations might occur in cricket maybe during fielding. As acute shoulder dislocations are traumatic, practising proper fielding diving technique is recommended as a preventive approach (Pardiwala et al., 2018).

Glenohumeral instability

Shoulder instability could be anterior, posterior or even multidirectional. Anterior instability is usually reported by the athlete following anterior glenohumeral dislocation and presents as a recurrent shoulder injury with repetitive subluxation (Smucny et al., 2016). Athletes with repetitive throwing workload may also present with the glenohumeral joint capsule laxity, and they may also present with anterior shoulder instability (Watson et al., 2016). Posterior and multidirectional instability among cricketers has a low prevalence rate and is mostly associated with ligament laxity and is often atraumatic in nature (Prabhakar and Pandey, 2015). Shoulder instability following a traumatic event as diving during fielding is often associated with labral tears and requires surgical intervention (Popp and Schöffl, 2015). Atraumatic shoulder dislocations could be associated with the repetitive throwing-bowling workload and ligament laxity. This could occur if the strength of the glenohumeral joint's static stabilisers are compromised. Strengthening of the rotator cuff and scapular muscles is advocated as a preventive method.

Muscle strains

Muscle tears and strains are also reported amongst cricketers. However, muscle tears of the biceps brachii and pectoralis major are mostly acute. They are commonly reported to occur during resistance training exercises in the gym and are very rarely reported to occur during cricket training or matches (Dhillon et al., 2012). Rotator cuff muscle tears could be either acute or chronic. Acute tears to the rotator cuff may occur due to forceful external rotation (Weiss et al., 2018) either while undergoing resistance training in the gym or it may also occur due to falling on the ground while fielding diving. Chronic rotator cuff injury is of gradual onset. It presents as rotator cuff inflammation at an early stage and presents with fraying of the tendons at a later stage and may progress into a partial or full tear (Seitz et al., 2011). Suggested preventative measures at early stages include rest (Mazuquin et al., 2018), reduced throwing-bowling workload and rotator cuff strengthening (Edwards et al., 2016). If

a tendon tear is detected, then surgical intervention is recommended as the best treatment option for the athlete (Brukner, 2012).

From reviewing the common shoulder conditions, it is understood that shoulder conditions could be either acute or overuse. In terms of shoulder injury prevention, acute shoulder injuries are difficult to predict and prevent as their onset is usually sudden and may occur at any stage during a match, training or even during resistance training sessions. Acute shoulder injuries in cricket have been predominantly reported to occur while falling on the ground (Pardiwala et al., 2018) while fielding-diving resulting in either a ligament sprain, muscle or labral tear or even involving dislocation and subluxation. Most acute shoulder injuries require surgical intervention, and the cricketer would not be able to undertake preventative steps to reduce their occurrence. Overuse injuries such as subacromial impingement, subacromial bursitis, and rotator cuff tendon conditions are all interrelated and preventive measures could be implemented to reduce their occurrence. Conservative exercise treatment methods implemented after an injury in the rehabilitation phase could also be modified and taught to the cricketer as part of a prehabilitation preventative measure.

Along with exercise-based prevention, understanding the cause of overuse injuries will aid in preventing their onset. Overuse injuries onset may be due to a variety of intrinsic and extrinsic risk factors, such as improper technique, increased throwing-bowling workload, reduced rest periods, ligament laxity, muscle strength and range of motion deficit (Olivier et al., 2016b). Exploring the various risk factors for shoulder injuries will aid in creating a targeted shoulder injury prevention programme.

2.5 Throwing and fast bowling in cricket

One of the better ways to understand shoulder injuries is to explore cricket throwing and fast bowling action.

To better understand the cricket throwing action, it is recommended to categorise and analyse the movement into different phases. The throwing action is commonly divided into four phases: Arm cocking; arm acceleration; arm deceleration and the final follow-through phase (Sachlikidis and Salter, 2007). During the arm cocking phase, the dominant shoulder is in abduction and external rotation, while the scapula is retracted with the elbow flexed. Mild

trunk flexion and same side lateral rotation are also observed, which creates a slinging effect. Major muscles such as the deltoids abduct the shoulder to 90°, and smaller rotator cuff muscles stabilise the shoulder (Cuéllar et al., 2017). This forceful abduction and external rotation during the arm cocking phase cause a posterior impingement of the rotator cuff tendon against the glenoid cavity by the humeral head. This impingement is a standard physical mechanism and only under repetitive overuse with low recovery periods does it manifest as a pathology.

The throwing action continues into arm acceleration phase, from the maximum external rotation to the release of the ball. The slinging effect from trunk rotation is used to increase the force used to propel the cricket ball (Laxmi et al., 2015). During ball release, glenohumeral internal rotation occurs with adduction. At the shoulder, the pectoralis major and internal rotators contract to create the force for throwing the ball. During this forced adduction and internal rotation, the external rotators maintain the humeral head position (Escamilla and Andrews, 2009). During repetitive throwing action, the rotator cuff has to counteract the force produced by the large pectoral and deltoid muscles. This repetitive stress on the rotator cuff fatigues the muscle. Repetitive fatigue produces muscle weakness, and it may contribute to glenohumeral instability due to long term throwing workload. After the ball is released in the deceleration phase, maximal glenohumeral internal rotation and elbow extension occurs continuing to the follow-through phase. During the deceleration phase, the external rotators eccentrically contract and resist the distraction force, which prevents anterior subluxation (Escamilla and Andrews, 2009), this eccentric contraction, when performed repetitively without enough rest periods leads to a chronic strain of the external rotators.

Fast bowlers are required to bowl the crucial overs in all cricket formats. Therefore, it is essential that alongside line and length, each delivery is bowled with a high pace. This repetitive bowling also may predispose the shoulder joint to structural adaptations. Hence, it is essential to understand the cricket fast bowling movement. The cricket fast bowling movement is a complex movement involving various phases before the final delivery of the ball. The bowling movement is initiated with a run-up to the bowling crease. The run-ups are the primary determinant of the delivery speed and increased ball velocity has been associated with faster and longer run-ups (King et al., 2016). Faster bowlers employ longer run-ups and faster approach velocities. The gained momentum is converted to a faster release velocity of the ball. During the run-up, fast bowlers have an average running speed of 4.77 - 6.76 m.s⁻¹

(King et al., 2016). The run-up transitions into the pre-delivery stride, the front foot is pushed high in the air, and the back foot contacts the ground with a completed leap. During the pre-delivery stride, the back foot on the right side of a right-handed bowler lunges forward and lands on the popping crease. The bowling action continues with the front foot contacting the popping crease, followed by the release of the ball and follow-through (Worthington, 2010).

Bowling mechanics play a vital role in injury prevention and developing correct bowling mechanics at an early junior cricket level will help the longevity of the fast bowler's playing career. Fast bowlers' actions are also classified through their foot placement and shoulder alignment. During the delivery phase, the back foot contacts the ground, and the bowlers lean backwards slightly with a change in the shoulder angle alignment (Roca et al., 2006). The shoulder alignment angle classifies the fast bowler's cricket bowling action as side-on (<210 degrees), mixed (210-240 degree) or front-on (>240 degrees) (Roca et al., 2006). The bowling shoulder follows a normal swinging movement until the back foot strikes the ground, circumduction at the glenohumeral joint starts between the back foot and front foot strike (Glazier and Wheat, 2014). The high-speed straight arm circumduction involves various actions at the glenohumeral joint. There is an initial shoulder abduction and external rotation during back foot strike followed by internal rotation and adduction this continues into arm extension, external rotation and finally internal rotation leading to the release of the cricket ball (Glazier and Wheat, 2014). The arm circumduction action also involves the explosive concentric and eccentric activity of the pectorals, deltoids and trapezius muscle to increase the ball release velocity (Ali et al., 2016). During the circumduction movement, the rotator cuff muscles also counteract with the large muscles to stabilise and rotate the glenohumeral joint (Elliott et al., 2002).

Observing the rotator cuff muscle's electromyographic (EMG) activity during cricket bowling action will help understand its role in glenohumeral joint stability. EMG studies conducted amongst 17 healthy cricket fast bowlers (Hazari et al., 2016) bowling bouncers, revealed that the supraspinatus showed peak activity (50.56 ± 13.46 RMS) during the arm acceleration phase and gradually reduced (42.78 ± 17.89 RMS) during the ball release phase. Whereas the infraspinatus activity was low (41.25 ± 18.5 RMS) during the acceleration phase, and it peaked (50.24 ± 24.08 RMS) during the ball release phase. As elite fast bowlers bowl hundreds of balls during a playing season, the supraspinatus and infraspinatus muscle has to repetitively contract and stabilise the glenohumeral joint during every rotational

movement. This concentric and eccentric activity of the supraspinatus and infraspinatus during cricket bowling exposes these muscles to repetitive stress. The study results also showed that the rotator cuff muscles counterbalanced the force created by the large deltoids during both phases of the bowling movement. When cricketers undergo repetitive bowling, the small rotator cuff muscles have to counter the large forces produced by the strong deltoids and pectoral muscle fibres. If the player does not undertake enough rest between training and matches, due to long term repetitive stress, the tissue strength of the rotator cuff tendons gets compromised. This may lead to a repetitive strain injury and may present as chronic shoulder pain for the fast bowlers (Dennis et al., 2005).

2.6 Pathomechanism of cricket shoulder injuries

To understand pathomechanism for overuse injuries, two principal elements have to be explored:

1. Insufficient or excessive workload; and
2. Inadequate mobility and strength.

Bowling and throwing workload is an extrinsic factor for shoulder injuries (Saw et al., 2011). Insufficient workload may not prepare the shoulder stabilisers to face the demands of a high pace bowling spell or sudden explosive fielding throwing. When an unconditioned tissue is exposed to sudden explosive movement, it may aggravate the soft tissues of the shoulder and cause an injury. Manipulating frequency, intensity and duration of exercise sessions and bowling trainings will help condition the soft tissues of the shoulder to meet the demands of high pace bowling spells and sudden explosive throwing actions.

Excessive overload places high stress over long periods on the soft tissues of the shoulder and does not allow enough time for the soft tissues to recover (Hulin et al., 2013). Different cricket boards have suggested recommendations based on age and playing levels for youth and adult cricketers. Bowling volume and throwing volume per day and per week, depending on the level of cricket played have also been recommended. Following these recommendations, along with workload monitoring, is essential for predicting injury risk and preventing injuries (McNamara et al., 2017).

This section explores the intrinsic factors for a shoulder injury. Muscle strength and range of motion assessments may help identify cricketers at risk of shoulder injuries. A 5-year retrospective study conducted in 2005 amongst 96 male South African cricketers reported 165 injuries, of which 40 (24%) were in the shoulder area. Eighteen of the 40 shoulder injuries were recurrent. Overall, bowlers experienced the highest number of shoulder injuries. Sixteen injuries occurred on the dominant arm and two on the non-dominant arm. The study identified glenohumeral internal rotation deficit as one of the primary risk factors for a shoulder injury. Additionally, fast bowlers in the study displayed reduced internal rotation and increased external rotation between their bowling and non-bowling shoulders. The study suggested a strong association between weak scapular stabilisers, reduced glenohumeral internal rotation and shoulder injury (Bell-Jenje and Gray, 2005).

The influence of shoulder rotational range of motion deficit to injury has been researched in other throwing sports. Position-based demands have been observed to cause structural adaptations in the glenohumeral joint. Baseball pitchers, in comparison to other baseball positions, exhibited 22° increased shoulder flexion and 21° increased external rotation at 90° shoulder abduction (Johnson, 1992). Two factors have been associated with shoulder injuries: first, a decreased joint range of motion and second, differences in the strength ratio between the shoulder internal and external rotators (Johnson, 1992, Cook et al., 1987). The difference in the strength ratio of the shoulder rotators has been attributed to the weakness of the internal rotators.

Cricket bowling and throwing actions involve repetitive glenohumeral rotations. Repetitive rotations and low recovery periods might cause fatigue to the rotator cuff muscles and lead to their weakness. The weakness of internal rotators has been shown to cause superior-anterior humeral head translation (Watts et al., 2017). Humeral head translations have been associated with impingement of the subacromial soft tissues such as the subacromial bursa and supraspinatus tendon (Hashiguchi et al., 2018). This overuse related injury pathology was observed amongst elite South African cricketers, where the majority of the cricketer's shoulder injuries involved impingement syndrome and rotator cuff pathology (Bell-Jenje and Gray, 2005).

Furthermore, to understand the pathomechanism of shoulder overuse injuries, the shoulder joint's dynamics needs to be analysed. As bowling and throwing action is dependent on the movement of the scapulothoracic and glenohumeral joint, any restriction in the joints would affect the bowling and throwing action. Scapulohumeral rhythm is a coordinated movement. The scapula glides and rotates laterally on the thoracic cage during glenohumeral abduction (Burkhart et al., 2003). For every 10 degrees of scapular rotation, there are 20 degrees of abduction at the glenohumeral joint. If a cricketer has a healthy uninjured shoulder, this 1:2 ratio must be displayed. Any underlying shoulder pathology will affect this ratio, or if this ratio is observed, then it means the cricketer may be at risk for shoulder injury (Timmons et al., 2012a). Impingement related pain has been linked to scapula dyskinesis (Lopes et al., 2015). Abnormal mobility of the scapula is defined as scapular dyskinesis (McClure et al., 2009).

Scapular dyskinesis is just an indication of the underlying pathology. Research suggests that a reduction in the subacromial space might be an outcome of scapular dyskinesis or vice versa (Depalma and Johnson, 2003). As scapular dyskinesis is linked to the reduction of subacromial space, there must be some translation of the humeral head in the superior anterior direction. If the rotator cuff muscles are strong, they will resist this translation. An association between scapular dyskinesis and rotator cuff strength deficit has been observed amongst overhead throwing athletes (Yu et al., 2016).

Strength deficits of the rotator cuff may impact glenohumeral joint stability. The compression provided by the static stabilisers (labrum, joint capsule and GH joint ligaments) and dynamic stabilisers (rotator cuff muscles) influences the glenohumeral joint stability (Yu et al., 2016, Taniguchi et al., 2017). Glenohumeral joint stability relies on the positioning of the humeral head in the glenoid cavity, and it is directly related to the force couple ratio between the internal and external rotators (Yu et al., 2016, Taniguchi et al., 2017). This force couple ratio also determines the availability of internal and external shoulder rotational ROM (Berckmans et al., 2017). Hence, it is suggested that chronic rotator cuff pathology will negatively affect the shoulder joint's rotation, and pain will be elicited during any abduction movement. This implies that if scapular dyskinesis is observed in a cricketer, the probability for any associated rotator cuff or subacromial pathology is likely. Therefore, including an assessment

of scapular dyskinesis during cricket pre-participation screening may identify intrinsic risk factors for a shoulder injury.

The shoulder joint's rotational ROM is reliant on the force produced by the rotator cuff muscles. If restrictions in the joint ROM are detected, it is advisable to explore the cause of the restriction. It is vital to find out if the deficit in ROM is due to muscle weakness/tightness or the joint's articular surface pathology. While throwing the cricket ball, the shoulder internal rotators concentrically contract to accelerate internal rotation motion and the external rotators eccentrically contract to maintain the joint stability during deceleration (Noffal, 2003). This deceleration is provided by the maintenance of the muscle strength ratio between the external and internal rotators for the effective functioning of shoulder rotation (Berckmans et al., 2017).

If muscle strength asymmetry exists between the external rotators and internal rotators over long periods, it will overload and stress the joint's static stabilisers (Kirchhoff and Imhoff, 2010). This imbalance might translate the humeral head anteriorly or posteriorly towards the side of the stronger muscle (Kirchhoff and Imhoff, 2010). The weakness of the external rotators could cause the humeral head to translate superiorly and anteriorly, reducing the subacromial space (Flatow et al., 1994). Commonly reported shoulder injury diagnoses such as subacromial impingement, subacromial bursitis and rotator cuff tendinopathy have all been associated with reduced subacromial space (Park, 2015). Athletes diagnosed with these overuse shoulder conditions have exhibited weakness of the external rotators (Laver et al., 2018). Hence, if a cricketer complains of chronic shoulder pain, presence of external rotator weakness is likely. Therefore, assessment of the rotator cuff muscle strength during cricket pre-participation screening may help identify intrinsic risk factors for a shoulder injury.

The identification of ROM restrictions is vital to identify joints at injury risk. Depending on the demands of the sport and playing position, adaptations may occur in a joint. Differences in the dominant and non-dominant arm's internal rotation ROM has been observed amongst overhead throwing sports athletes (Scher et al., 2010). A 2008 study, reported that cricketers who exhibited internal rotation deficit of 10° also complained of pain on the same shoulder (Stuelcken et al., 2007), as shown in Table 2.4. This suggests that if a player displays an

internal rotation deficit of more than 10°, precautions must be undertaken to reduce shoulder injury risk for the player.

In contrast, a study amongst male cricketers in 2004, concluded that rotational ROM is not associated with shoulder pain (Aginsky et al., 2004). Some research suggests that an increase in external rotation and a decrease in the internal rotation may not be a significant contributor to shoulder injuries (Aginsky et al., 2004). It is unclear if rotational deficits are the cause for shoulder injuries or if shoulder injuries cause a decrease in rotation ROM. Among baseball pitchers, if a bilateral internal rotation difference of more than 15° exists between the dominant and non-dominant shoulder, it is termed glenohumeral internal rotation deficit (GIRD) (Manske and Ellenbecker, 2013). Studies have also proposed that a GIRD of more than 15° alters scapulohumeral rhythm (Thomas et al., 2010). Changes to the scapulohumeral rhythm may indicate an underlying pathology either in the scapulothoracic or glenohumeral joints.

The reviewed literature suggests that ROM may be affected by repetitive throwing and bowling. Frequent throwing and bowling may induce repetitive stress and may cause adaptations to the joint's soft tissues. As the dominant arm is most likely used for throwing and bowling, bilateral ROM differences are likely to exist. Similarly, players who bowl a high number of balls in trainings and matches may exhibit bilateral ROM differences (Hulin et al., 2014b). It is hard to stop these structural adaptations in the shoulder joint because of the demands of cricket, but periodic screening of ROM and muscle strength may help identify cricketers at risk for shoulder injuries. Based on the screening results, preventative steps could be initiated for those players.

Table 2.4. Cricket players shoulder rotational ROM differences

Author, year	Cohort	Injured players	Uninjured players
Sundaram et al., 2012b	Cricket bowlers (n=66) (age 19 ± 2 years)	NA	(Spin bowlers) Bilateral IRD of 12.9° , ERD of 23.46° (Fast bowlers) Bilateral IRD of 11.58° , ERD of 15.23°
Giles and Musa, 2008	Male & female cricketers (n=133) (age 18 ± 6 years)	NA	Bilateral IRD of -7.9° Bilateral ERD of 8.6°
Stuelcken et al., 2007	Female fast bowlers (age 23 ± 5 years)	(n=12) Active ER ROM $83 \pm 13^\circ$ Active IR ROM $43 \pm 6^\circ$	(n=14) Active ER ROM $89 \pm 9^\circ$ Active IR ROM $44 \pm 9^\circ$
Aginsky et al., 2004	Male fast bowlers (age 22 ± 5 years)	(n=9) Passive ER ROM $116 \pm 10^\circ$ Passive IR ROM $84 \pm 11^\circ$	(n=12) Passive ER ROM $117 \pm 8^\circ$ Passive IR ROM $90 \pm 17^\circ$

Abbreviations: IRD, Internal rotation difference; ERD, External rotation difference; ROM, Range of motion; IR, Internal rotation; ER, External rotation

2.7 Exercise-based shoulder injury prevention

Shoulder injuries in fast bowlers are predominantly non-contact overuse injuries (Sharma et al., 2012) involving the rotator cuff muscle. Exercise-based interventions have been developed to prevent repetitive strain injuries in non-contact sports (van Beijsterveldt et al., 2013). Manipulation of the right amount of exercise intensity, frequency and duration have been researched to quickly strengthen the muscle and ensure the reduction in injury incidence (Mascarin et al., 2017). Eccentric strengthening exercises have been explored to reduce injuries in several sports such as hamstring injuries in sprint-based sports, adductor injuries in agility based sports and shoulder muscle injuries in overhead motion sports (Bourne et al., 2018). Implementation of exercise-based injury prevention programmes has previously been shown to be effective in reducing injury risk by 32% in community-level adolescent athletes (Finch et al., 2003). Exercise-based injury prevention programmes such as FIFA 11 is implemented even for community-level football teams (Bizzini and Dvorak, 2015). This exercise-based injury prevention programme has been estimated to reduce community-level football injuries.

Currently, there are no widely used injury prevention programmes for cricket. Exercise-based injury prevention programmes for preventing thigh and back injuries have been researched and experimented among various cricket cohorts, but very few studies have targeted the shoulder area. The eccentric weakness of the shoulder's external rotators causes an imbalance in the internal/external rotator muscle strength which has been acknowledged to contribute to shoulder injuries (Mulligan et al., 2004, Bayios et al., 2001, Vodička et al., 2018). To date, there are no studies investigating the effects of exercise on rotator cuff strength asymmetry in cricket. Correcting the shoulder rotator muscle strength asymmetry has been experimented in several other sports. Exercise-based injury prevention programmes using resistance bands to strengthen the rotator cuff muscles have been shown to bring beneficial outcomes (Mascarin et al., 2017). As the subscapularis muscle is a larger muscle than the infraspinatus and teres minor, it produces large amounts of force, leading to a stronger internal rotation. Stronger internal rotators contribute to superior anterior translation of the humeral head leading to joint instability. Hence, exercises to strengthen the external rotators are suggested to balance the force couple ratio between the external and internal rotators.

College-level tennis players involved in a five-week resistance band shoulder strengthening programme displayed significant gains in their eccentric external rotator strength (Shim and Niederbracht, 2014). A 20% increase in the average force of the external rotators was measured after collegiate baseball pitchers were involved in a six week exercise period (Marsh et al., 2018). This suggests that the external rotators can be strengthened using exercises for cricket fast bowlers as well.

As cricket throwing and bowling involve frequent rotational movements, it causes fatigue to the rotator cuff muscles (Saw et al., 2011). Also, as internal rotation movement produces more force compared to external rotation, it may further strengthen the internal rotators. By nature, the internal rotators are stronger. Adaptation to the demands of the cricket throwing and bowling further strengthens the internal rotators. This may cause an imbalance in the internal-external rotator force couple ratio. If this muscle strength asymmetry exists for long periods, it may cause further detrimental changes to the soft tissues of the shoulder joint (Cook et al., 1987). Stronger internal rotators are associated with superior anterior humeral translation. The humeral translation is associated with the reduction of the subacromial space. Reduction of the subacromial space may cause compression of the subacromial soft tissues

(Page, 2011). This may cause chronic shoulder pain for the fast bowler. Hence, screening for shoulder-rotator muscle strength asymmetry and undertaking exercise-based interventions to correct the asymmetry is recommended for prevention of overuse shoulder injuries. As there are no such evidence-based shoulder exercise programmes specific to the cricketers' shoulders, it is recommended that this be undertaken.

CHAPTER THREE

Studies

3.1 Preface to study one

This section of the thesis relates to the first specific aim of the thesis:

To determine how many cricket-related injuries are occurring among New Zealand's general population

Cricket is a predominantly summer sport in New Zealand. Nationwide, cricket is played across various levels, from primary school level to elite first-class level. With such nationwide participation across the country, injuries are likely to occur. To reduce cricket-related injury incidence, it is essential to quantify the extent of those injuries and identify injury cause. Without identifying the injury cause it is difficult to implement injury prevention methods. All existing cricket injury studies have been conducted across elite or sub-elite cohorts. While the knowledge obtained from elite cricket injury studies is essential for cricket injury prevention, the cause of cricket-related injuries amongst a nationwide population may differ from elite cohorts. Therefore, it is necessary to quantify cricket-related injuries across the country.

Currently, there are no nationwide cricket injury surveillance reports which cover all levels of cricket. Hence, the extent of cricket-related injury problem across all levels must be quantified. According to van Mechelen's sports injury prevention model (van Mechelen et al., 1992), the first stage is quantifying the extent of the sports injury problem. In relation to this, the first study of this thesis was aimed at finding out how many injuries has occurred nationwide, over a 12 year period, due to cricket participation. As everyone from a weekend recreational cricketer to a national level representative cricketer is included in nationwide injury surveillance, this would be able to capture cricket-related injuries across all age groups and all levels of the sport. The results of the study would identify the most injured age group and body area. Besides, the results of the study would isolate and reveal the exact cause of injury onset. Based on this study's findings, the consecutive studies in this thesis will focus on exploring the aetiology of shoulder injuries.

3.1.1 Study 1

Cricket injuries in New Zealand: A review of twelve years of Accident Compensation Corporation injury entitlement claims

Abstract

Background: Cricket is a summer sport enjoyed by millions globally with high public participation rates across the globe. Given the popularity of cricket, it is somewhat surprising that most injury surveillance reports have focused only on elite or sub-elite cohorts. To improve the understanding of cricket injury aetiology and to quantify nationwide cricket injury prevalence, studying cricket-related injuries amongst the general public is essential. Therefore, this study was aimed to address these research gaps by quantifying cricket-related injuries in New Zealand (NZ) population from the years 2005 to 2016.

Methods: Data of cricket-related injury claims were obtained from the NZ Accident Compensation Corporation (ACC) and were then categorised by injured age groups, affected body areas, injury type and diagnosis. Based on the NZ population censuses, the age-standardised injury incidence (ASII) per 10,000 people-years was calculated using the Segi world standard for each calendar year. Each categorised grouping was then divided by the sum of the total injuries and presented as a percentage.

Results: A total of 77212 injuries were recorded, and the ASII increased by 42% over the 12 years (2771 in 2005 to 3936 in 2016 - per 10,000 people-years). Notably, age groups 10-14 (16.8%) and 15-19-years (17.5%) had the highest injury prevalence. Soft tissue injuries (76%) were the highest injury type, and 69% of all injuries were due to contact. The remaining 31% of all injuries were from a non-contact cause, and non-contact injuries were mainly caused due to repetitive strenuous movement. The back/spine (31.4%) and shoulder (20.2%) experienced the highest non-contact injury prevalence, and in comparison to other injured body areas, the shoulder (84.6%) and back/spine (75.7%) displayed the highest increase in injury prevalence during the 12 years.

Conclusion: Implementing an effective injury prevention programme relies on the identification of injury-prone body areas. The study results indicate that non-contact soft tissue injuries to the shoulder and spine require attention as these body areas experienced the highest increase in injury prevalence over the 12 years.

3.1.1.2 Introduction

Cricket is a popular summer sport traditionally played in the Commonwealth nations (Khondker and Robertson, 2018). New Zealand's domestic cricket season runs from October to March and incorporates all outdoor formats of the game. Cricket is played across all levels in the country, starting from primary school cricket, recreational weekend cricket to elite first-class cricket. The introduction of a shorter T20 game format along with internet streaming of cricket matches has coincided with the increased popularity of cricket and has led to large participation numbers (Khondker and Robertson, 2018). In NZ, the nationwide cricket participation numbers increased by 75% with 97000 people registered to play cricket during the years 2005-2006 to over 170000 registered to play during the years 2014-2015 (Archive NZC, 2015). With sizeable public participation numbers, it is essential to monitor potential injury risk to ascertain if there is a widespread sports injury problem. The van Mechelen's model (van Mechelen et al., 1992) emphasises that the first stage to sports injury prevention is, identifying the extent of the problem. Quantification of a sports injury problem can be done only through sports injury surveillance.

Injury surveillance studies amongst elite cricketers have identified the most injury-prone player positions, body areas and injury frequency. Specifically, during the years 1995 to 2001, a total of 527 injuries were reported among Australian first-class cricketers with a match injury incidence rate of 20.4 injuries/10000 player hours (Orchard et al., 2002). As surveillance studies quantified injury frequency, it was also necessary to explore the injury cause. A South African injury surveillance report of under 18 provincial age-group cricketers highlighted that 45% of all injuries occurred while bowling (Stretch, 2018).

Furthermore, studies have also identified the most injured body areas. In NZ, a seven-year study amongst 248 male cricketers revealed that the most frequently injured body areas were the thigh (17.1%), low back (14.2%) and hand (9.2%) (Frost and Chalmers, 2014). Establishing injury predisposition is necessary to assess injury risk. Hence, during the 2007-2008 cricket season, observations from 28 elite male Australian cricketers revealed that players were at an increased risk of upper limb injury if they completed more than 75 throws/week (RR = 1.73, 95% CI = 1.03 to 2.92) (Saw et al., 2011). Along with these findings it was also noted that surveillance studies during short international tournaments (5.1%) reveal a lower injury prevalence (Ranson et al., 2013) in comparison to year-long injury

surveillances (12.5%) (Orchard et al., 2016a). These injury surveillance findings provide evidence for designing elite cricket injury prevention strategies. Even though there is plenty of published research on elite cricket injuries, much less is known about the nationwide cricket-related injury incidence. For epidemiological reasons, injury type, injury onset, injury prevalence rate and injury mechanism could differ between the elite cricketing population and a nationwide cricket playing population.

As cricket is classified as a non-contact sport, the chances for acute injuries due to impact with objects are higher than experiencing an injury due to collision with another player (Olivier et al., 2016b). Therefore, when conducting cricket injury surveillance, if the nature of the acute injuries is reported as either contact or non-contact injury, it will help in modifying the preventative strategies based on that. For example, with regards to finger injuries, elite players may utilise recommended ball-catching techniques more frequently and have better access to protective sports equipment, thereby minimising injury risk (Orchard et al., 2002). In comparison, recreational cricket players may not follow the recommended catching techniques as often and may not have the same access to protective equipment. In such a case, generalising injury aetiology of elite cricketers to a nationwide cricketing population might not be applicable. Elite cricketers also undergo intense workload, play frequent matches and training, thereby increasing their predisposition to overuse injuries (Dennis et al., 2005) while recreational cricketers may not involve in regular warmup or conditioning sessions and may just play during the weekends, which may lead exposing themselves to sudden loading and acute injuries.

Injury prevalence rates specific to body areas between elite cricketers and recreational cricketers would also differ. Elite cricketers may not experience impact related face or finger injuries as often as recreational cricketers, in contrast, elite cricketers may encounter overuse related injuries to the spine or shoulder (Dennis et al., 2005). Elite cricketers will face faster balls and play a greater number of balls, so may have greater exposure to injuries in comparison to recreational cricketers (Saw et al., 2011). In such a case, a cricket injury surveillance report of elite cricketers may reveal a higher prevalence of spine and shoulder overuse injuries, whereas, amongst a nationwide cricketing population, face or finger impact injuries may have a higher prevalence. Hence, while conducting cricket injury surveillance, it is critical to question the nature of the reported injury at all levels of the sport.

Currently, there is no published nationwide study reporting on injury prevalence across all levels of cricket. In NZ, the last published cricket injury surveillance study was in 2008, and it was focussed solely on elite cricketers (Frost and Chalmers, 2014). Given the popularity of cricket in NZ, quantifying nationwide cricket injury prevalence will help understand cricket injury aetiology. Therefore, the specific objective of this study was to quantify and analyse all cricket-related injuries in the NZ population requiring medical treatment from the years 2005 to 2016.

3.1.1.3 Methods

Study design

Observational descriptive study

Participants

After consulting with the University of Canterbury Ethics committee, a formal application was made to ACC to obtain claimant suppressed de-identified data. The University of Canterbury Ethics committee and ACC did not require ethics application as the obtained data was secondary de-identified claimant suppressed information. Therefore, male NZ residents who claimed medical treatment and rehabilitation costs from New Zealand's ACC for a cricket-related injury from the years 2005 to 2016 were included in this study.

Data collection

Currently, the national cricket organisation does not capture nationwide cricket-related injury data across all levels of cricket. Therefore, the ACC database was procured to describe the epidemiological extent of cricket-related injuries during the 12 year study period. New Zealand's Accident Compensation scheme has provided the accident insurance cover for all NZ citizens and residents from the year 1974. A claim to ACC is made when seeking medical treatment from a registered health professional. A standard ACC 45 injury claim form is completed by the injured person with personal details and injury information (date, location, activity, the cause of injury and sport at the time of injury) and the registered medical practitioner inputs the information relating to injury diagnosis and the medical care provided. The compensation covers costs toward medical treatment and rehabilitation (King et al.,

2009). Cricket injury data relating to only male residents were obtained for the sake of this study.

Injury definition

The injury definition used for the current study is *“any new cricket-related injury, which has been assessed and reported by a registered medical practitioner in NZ, and has been recorded as an ACC injury claim.”*

Statistical analyses

Data obtained from ACC was entered into a Microsoft Excel spreadsheet and was divided into variables such as injured year, age group, injured body area, diagnoses, and injury type. Only male injury claims related to outdoor cricket were used in this study. Only new injury claims from the years 2005 to 2016 were considered; all previous injury claims data were removed from the data so that incidence rate could be calculated only for fresh injury claims for each calendar year.

The total number of people registered to play cricket, over the 12 year study period was not documented in NZ. Hence, a common denominator to calculate the nationwide injury incidence was unavailable. Nevertheless, any NZ resident experiencing a sports injury during the 12 year study period was entitled to make an ACC injury claim. Therefore, the 2006 and 2013 NZ resident population censuses data were used as a common denominator to calculate the injury incidence.

Comparisons of injury incidence rates across different periods require techniques that adjust for variations in the age structure of populations. Also, as the study participants include both Māori and non-Māori injury claimants, the considerable difference in age structure between an indigenous and non-indigenous population of Aotearoa/ New Zealand (Robson et al., 2007) requires age standardisation. Hence, Segi’s world standard population (Standard Populations (Millions) for Age-Adjustment - SEER Population Datasets, 2019) was used to standardise the population in this study (Waterhouse, 1982, Segi, 1969). Segi’s “world” standard population is standardised, based on the pooled population from 46 countries, used globally as a reference population to obtain age-standardised incidence for an observed population (Waterhouse, 1982, Segi, 1969).

The standardised incidence was calculated using the following steps.

As an illustration for the year 2016, the standardised incidence of injuries was calculated as below using the 10-14 year old age group as an example:

Step 1: Total number of cricket injuries for the 10-14 year old age group was 1216

Step 2: 2013 NZ census population for the 10-14 year old age group males was 146670

Step 3: Age-specific incidence is calculated as $1216/146670 = 0.008291$

Step 4: Segi world standard for the 10-14 year old age group is 9

Step 5: Age-standardised count is $0.008291 * 9 = 0.074616$

Step 6: Age-standardised injury incidence for 10,000 people/year is $0.074616 * 10,000 = 746.2$

The injury/body area and injury/diagnosis percentages were calculated using the following steps:

An illustration for calculating shoulder injury percentage is shown below

Step 1: Total number of cricket shoulder injuries for the year 2015 was 902

Step 2: The total number of injuries for 2015 was 7619

Step 3: The shoulder injury percentage was calculated as $902/7619$

Step 4: The shoulder injury percentage for 2015 is 11.8 %

Some of the injured body parts were grouped and separated into 12 main body areas, due to fewer injuries in certain body parts, the grouped body parts are listed below:

1. Wrist/hand injuries (wrist, hand, fingers and thumb)
2. Hip/thigh injuries (abdomen, pelvis, hip, thigh and upper leg)
3. Back / spine injuries (lower back, spine, and cervical vertebrae)
4. Upper / lower arm injuries (elbow, upper and lower arm)
5. Lower leg/foot injuries (foot, toe and lower leg)
6. Face injuries (ear, eye, nose and face)
7. Other injuries (internal organs, multiple locations and unknown)
8. Shoulder injuries
9. Knee injuries
10. Ankle injuries
11. Chest injuries
12. Head injuries

The different injury causes were broadly grouped into contact, non-contact and others injuries the grouped injury types are listed below:

1. Non-contact injuries

- a. Repetitive movement
- b. Strenuous movement without lifting
- c. Strenuous movement with lifting
- d. Caused own injury without tool

2. Contact injuries

- a. Collision
- b. Impact with object
- c. Impact with ground
- d. Contact with person
- e. Contact with a moving object
- f. Contact with object carried
- g. Dropped object
- h. Falling objects not handled
- i. Flying objects
- j. Unclear contact
- k. Contact while handling

3. Other injuries

- a. Environmental elements
- b. Medical treatment
- c. Inhaled/ swallowed substance
- d. Step on a sharp object
- e. Drove into object
- f. Other moving part

3.1.1.4 Results

A total of 77212 cricket injuries were recorded over the 12 years, and during those years the injury incidence increased by 42% (2771 in the year 2005 to 3936 in 2016 – injuries per 10000 people) as shown in Table 3.1. Throughout the 12 years, the age groups 10-14 and 15-19 were the most injury-prone due to cricket participation. Also, among the most injured age groups, an increase in injury incidence of 37% was observed among the 10-14 year olds (513 in the year 2005 to 746 in 2016 – injuries per 10000 people).

Table 3.1. Age-standardised cricket-related injury incidence per 10,000 people-years

Age group	2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		2016	
	n	Incidence	n	Incidence	n	Incidence	n	Incidence	n	Incidence	n	Incidence	n	Incidence	n	Incidence	n	Incidence	n	Incidence	n	Incidence	n	Incidence
00-04	25	21.4	11	9.4	21	18.0	27	23.1	15	12.8	10	8.5	10	8.0	9	7.2	14	11.3	11	8.8	13	10.4	14	11.3
05-09	213	145.4	169	115.3	243	165.8	234	159.7	245	167.2	255	174.0	240	164.2	211	144.3	209	143.0	217	148.4	297	203.1	262	179.2
10-14	896	513.3	967	553.9	1081	619.2	1083	620.4	1088	623.2	1067	611.2	975	598.3	1105	678.1	1095	671.9	1131	694.0	1237	759.1	1216	746.2
15-19	932	550.3	938	553.8	1222	721.5	1163	686.6	1186	700.2	1147	677.2	1061	632.8	1201	716.2	1213	723.4	1152	687.0	1223	729.4	1093	651.8
20-24	744	440.6	707	418.7	832	492.7	830	491.5	890	527.1	842	498.7	756	415.4	854	469.3	934	513.2	940	516.5	1006	552.8	947	520.4
25-29	605	412.9	676	461.4	781	533.0	877	598.6	919	627.2	874	596.5	750	480.2	790	505.8	853	546.1	928	594.1	1031	660.1	945	605.0
30-34	458	210.0	494	226.5	535	245.3	586	268.6	650	298.0	698	320.0	634	312.1	707	348	780	383.9	786	386.9	780	383.9	774	381.0
35-39	330	138.5	351	147.3	420	176.2	458	192.2	551	231.2	505	211.9	511	242.6	513	243.6	530	251.7	557	264.5	612	290.6	626	297.2
40-44	297	118.1	306	121.7	364	144.7	381	151.5	409	162.6	413	164.2	402	167.4	429	178.7	469	195.3	530	220.7	538	224.0	517	215.3
45-49	253	106.1	251	105.3	296	124.2	333	139.7	319	133.8	303	127.1	245	101.8	301	125.1	339	140.9	369	153.4	429	178.3	387	160.9
50-54	143	57.5	154	61.9	162	65.2	168	67.6	162	65.2	158	63.6	137	47.4	186	64.3	214	74.0	202	69.9	212	73.3	243	84.0
55-59	71	24.6	84	29.2	113	39.2	101	35.1	106	36.8	107	37.1	82	26.0	99	31.4	106	33.6	102	32.3	108	34.2	122	38.7
60-64	44	19.9	51	23.1	62	28.1	53	24.0	69	31.2	54	24.5	58	20.4	63	22.1	81	28.4	62	21.8	60	21.1	58	20.4
65-69	16	6.7	25	10.4	32	13.3	28	11.6	26	10.8	27	11.2	28	8.8	31	9.7	34	10.7	28	8.8	37	11.6	52	16.3
70-74	13	4.7	9	3.2	21	7.5	12	4.3	15	5.4	12	4.3	12	3.3	19	5.3	12	3.3	15	4.2	23	6.4	18	5.0
75-79	1	0.2	2	-	7	1.5	5	1.1	6	1.3	8	1.7	11	2.2	7	1.4	13	2.6	2	-	6	1.2	15	3.0
80-84	3	0.5	2	-	2	-	1	-	1	-	2	-	1	-	2	-	4	0.6	1	-	6	0.8	3	-
85+	-	-	2	-	-	-	3	-	1	-	2	-	2	-	-	-	1	-	-	-	1	-	3	-
Total	5044	2771	5199	2842	6194	3396	6343	3476	6658	3634	6484	3532	5915	3231	6527	3551	6901	3734	7033	3812	7619	4140	7295	3936

n = total number of injuries

Over the 12 year period the highest increase in injury prevalence due to cricket participation was observed in the shoulder (85% increase, 468 injuries in 2005 to 864 injuries in 2016) and back/spine (77% increase, 718 injuries in 2005 to 1262 injuries in 2016) as shown in Table 3.2. All body areas showed an increase in injury prevalence during the 12 year period except injuries to the face, which decreased by 15% (644 injuries in 2005 to 546 injuries in 2016).

Table 3.2. Cricket-related injury prevalence by body area

Year	2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		2016		12- year total	
Body area	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Wrist/ hand	956	19.0	1013	19.5	1233	19.9	1260	19.9	1335	20.1	1245	19.2	1196	20.2	1344	20.6	1273	18.4	1331	18.9	1508	19.8	1485	20.4	15179	19.7
Back/spine	718	14.2	749	14.4	826	13.3	1006	15.9	992	14.9	950	14.7	869	14.7	1009	15.5	1201	17.4	1217	17.3	1298	17.0	1262	17.3	12097	15.7
Shoulder	468	9.3	503	9.7	682	11.0	680	10.7	716	10.8	700	10.8	687	11.6	754	11.6	803	11.6	877	12.5	902	11.8	864	11.8	8636	11.2
Knee	538	10.7	534	10.3	680	11.0	639	10.1	673	10.1	674	10.4	658	11.1	739	11.3	754	10.9	785	11.2	808	10.6	790	10.8	8272	10.7
Face	644	12.8	570	11.0	704	11.4	685	10.8	708	10.6	678	10.5	578	9.8	535	8.2	499	7.2	528	7.5	572	7.5	546	7.5	7247	9.4
Hip/thigh	407	8.1	458	8.8	479	7.7	497	7.8	547	8.2	532	8.2	459	7.8	585	9.0	609	8.8	605	8.6	648	8.5	597	8.2	6423	8.3
Lower leg/ foot	346	6.9	397	7.6	492	7.9	471	7.4	476	7.1	533	8.2	433	7.3	488	7.5	560	8.1	519	7.4	588	7.7	523	7.2	5826	7.5
Ankle	354	7.0	357	6.9	402	6.5	422	6.7	467	7.0	458	7.1	444	7.5	447	6.8	529	7.7	478	6.8	538	7.1	509	7.0	5405	7.0
Upper/lower arm	215	4.3	227	4.4	265	4.3	250	3.9	268	4.0	301	4.6	228	3.9	267	4.1	314	4.6	286	4.1	323	4.2	294	4.0	3238	4.2
Others	179	3.5	187	3.6	217	3.5	197	3.1	207	3.1	171	2.6	163	2.8	142	2.2	142	2.1	167	2.4	170	2.2	172	2.4	2114	2.7
Chest	137	2.7	133	2.6	146	2.4	157	2.5	177	2.7	165	2.5	134	2.3	145	2.2	144	2.1	161	2.3	165	2.2	166	2.3	1830	2.4
Head	82	1.6	71	1.4	68	1.1	79	1.2	92	1.4	77	1.2	66	1.1	72	1.1	73	1.1	79	1.1	99	1.3	87	1.2	945	1.2
Total	5044	100	5199	100	6194	100	6343	100	6658	100	6484	100	5915	100	6527	100	6901	100	7033	100	7619	100	7295	100	77212	100

n = number of injuries

From the 77212 cricket injuries recorded over the 12 years, 69% were contact injuries while 31% were non-contact injuries. The wrist area was highly prone to contact injuries in comparison to other body areas, while non-contact injuries were more prevalent in the back/spine and shoulder, as shown in Table 3.3.

Table 3.3. Cricket-related injury type by body area

Body area	Non-contact		Contact		Others	
	n	%	n	%	n	%
Wrist/ hand	793	3.4	14354	26.9	32	8.4
Back/spine	7396	31.4	4676	8.8	25	6.5
Shoulder	4768	20.2	3850	7.2	18	4.7
Knee	2620	11.1	5633	10.6	19	5.0
Face	72	0.3	7161	13.4	14	3.7
Hip/ thigh	2981	12.7	3427	6.4	15	3.9
Lower leg/ foot	1400	5.9	4314	8.1	112	29.2
Ankle	1593	6.8	3789	7.1	23	6.0
Upper/lower arm	852	3.6	2371	4.5	15	3.9
Others	593	2.5	1419	2.7	102	26.6
Chest	474	2.0	1351	2.5	5	1.3
Head	11	-	931	1.7	3	0.8
Total	23553	100	53276	100	383	100

n = number of injuries

Majority of all cricket related soft tissue injuries occurred on the back/spine, while the wrist/hand experienced the highest number of fractures and dislocations. Injury due to gradual inflammation was only recorded on the shoulder and arms, as shown in Table 3.4.

Table 3.4. Cricket-related injury diagnosis by body area

	Soft tissue injury		Fracture/dislocation		Laceration/puncture		Dental injury		Unknown		Concussion		Others		Gradual inflammation	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Back/spine	12068	15.6	26	0	3	0	-	-	-	-	-	-	-	-	-	-
Wrist/hand	8609	11.1	5182	6.7	1358	1.8	-	-	19	0	-	-	3	-	8	0
Shoulder	7950	10.3	634	0.8	10	0	-	-	-	-	-	-	-	-	42	0.1
Knee	7610	9.9	305	0.4	334	0.4	-	-	20	0	-	-	3	0	-	-
Hip/thigh	6288	8.1	37	0	56	0.1	-	-	28	0	-	-	14	0	-	-
Ankle	5253	6.8	136	0.2	13	0	-	-	2	0	-	-	1	0	-	-
Lower leg/foot	4138	5.4	703	0.9	971	1.3	-	-	3	0	-	-	11	0	-	-
Face	2377	3.1	492	0.6	1922	2.5	2347	3	30	0	-	-	79	0.1	-	-
Upper/lower arm	2325	3.0	397	0.5	452	0.6	-	-	1	0	-	-	2	0	61	0.1
Chest	1480	1.9	273	0.4	66	0.1	-	-	10	0	-	-	1	0	-	-
Others	384	0.5	43	0.1	180	0.2	-	-	1432	1.9	-	-	54	0.1	21	0
Head	264	0.3	22	0	234	0.3	-	-	-	-	424	0.5	1	0	-	-
Total	58746	76.1	8250	10.7	5599	7.3	2347	3	1545	2	424	0.5	169	0.2	132	0.2

n = number of injuries

Among the four most injury-prone body areas over the 12 year period, the highest increase in injury prevalence due to cricket participation was observed in the shoulder (85% increase, 468 injuries in 2005 to 864 injuries in 2016) and back/spine (77% increase, 718 injuries in 2005 to 1262 injuries in 2016)

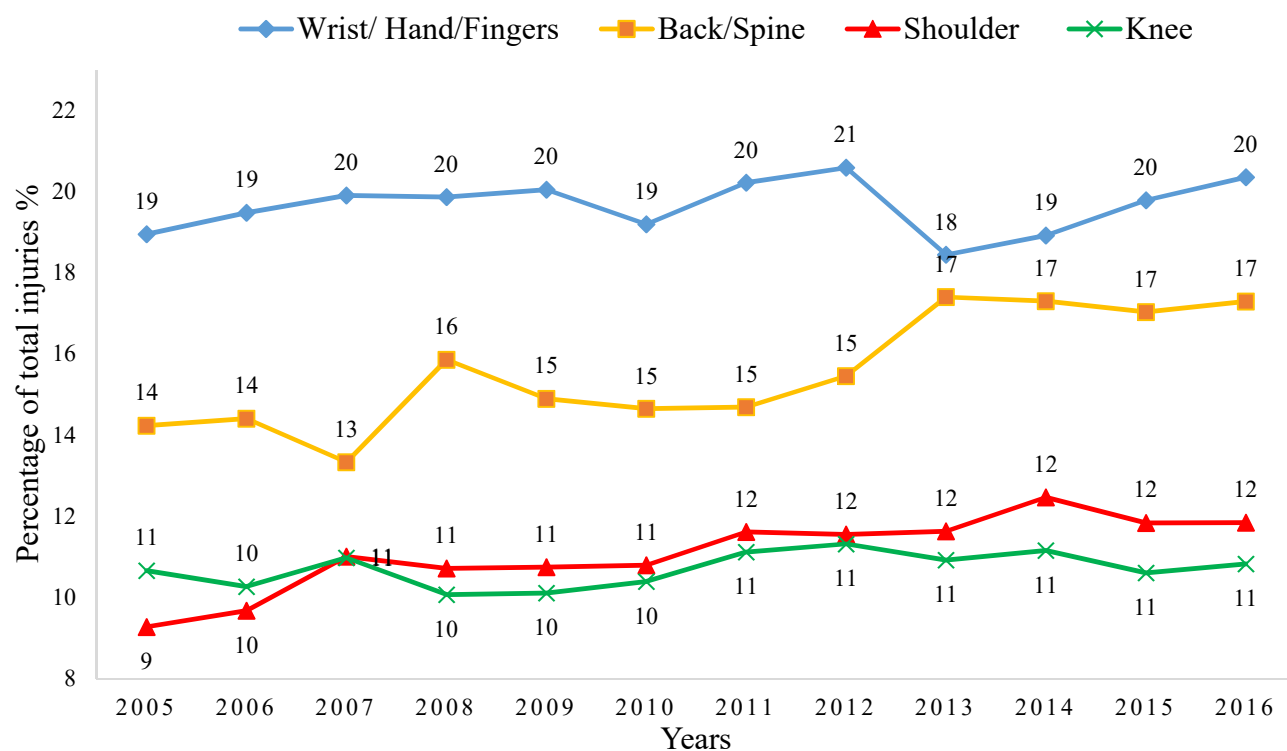


Figure 3.1. Cricket-related injury prevalence of the most injury-prone body areas during the 12 years

3.1.1.5 Discussion

The focus of this study was to highlight the nationwide cricket injury prevalence, as well as describe the nature of those injuries. This study provided an epidemiological description of cricket-related injuries among the NZ resident population from the years 2005 to 2016 and was the first study to provide an insight into such a large cohort associated with cricket injuries.

The age-standardised injury incidence for the nationwide male cricket playing population increased by 45% with 2771 injuries per 10000 people in the year 2005 to 3935 injuries per 10000 people in the year 2016 as shown in Table 3.1. During the 12 year period, there was a substantial increase in injury incidence. The introduction of T20 cricket format along with the availability of streaming international cricket matches may have caused a surge in the popularity of the sport and might have led to large participation numbers. A comparison is also shown in an analysis of injuries amongst Australian cricketers over 11 seasons where it is suggested that there was a 10% increase in prevalence rates from 2005 to 2009 due to the increased playing schedule for first-class cricketers (Orchard et al., 2010). This is reflective of the shorter format cricket competitions introduced across different levels of cricket such as club cricket, school cricket, regional cricket and metro cricket. While it is hard to discern what could have caused the 45% increase in injury incidence rate, the answer might also be due to a direct increase in participation numbers across the country. Further research is required to formally collect cricket participation numbers across the country during the 12 year period and also to find out the reason behind the increased participation numbers.

Results of the study revealed that the age group of 10-14-year-olds are consistently the most injury-prone (16.8%) group over the 12 year period. Even after adjusting the population growth, there was still a 30% increase in injuries among 10-14-year-olds between the years 2005 to 2016. Typically there is an observed increase in the frequency of sports participation in the 10 to 20 year age group. Adolescent athletes of this age group can encounter more epiphyseal and stress injuries due to the undergoing hormonal changes (Frush and Lindenfeld, 2009). Also, the opportunity to play cricket at various levels such as school cricket, club cricket, recreational weekend cricket and regional age-group cricket all contribute to increased cricket participation in this age group. More frequent participation and training can improve skill development and provide opportunities for some to represent at a

regional or national level. At the same time, it should also be noted that injury onset at a younger age will also affect performance and can prevent further participation in the sport. Commonly reported adolescent sports injuries such as osteochondritis dissecans, epiphyseal fractures, apophysitis and other lower limb repetitive strain injuries had been well documented to cause early degenerative changes (Frush and Lindenfeld, 2009). Hence, monitoring this injury-prone age group of 10 to 14-year-olds and implementing early preventative strategies is strongly recommended.

Ranking the percentage of injuries by body areas across the 12 years reveals that the hand (19.7%), back /spine (15.7%), shoulder (11.2%) and knee (10.2%) are the most frequently injured areas. The prevalence of cricket-related hand injuries seen in the nationwide NZ population is twice higher than the NZ elite cricketers' injury prevalence of 9.2% (Frost and Chalmers, 2014). Of the recorded 15179 hand injuries, majority of those injuries (14354) were due to contact with either an object, ground or person, in comparison to only 793 non-contact injuries as shown in Table 3.3. This pattern of wrist and hand injuries is also seen amongst elite cricketers (Frost and Chalmers, 2014, Orchard et al., 2002, Ranson et al., 2013). It may be that contact and impact with the ball or falling with an outstretched arm all contribute to impact-related injuries at all levels of cricket. In Table 3.4, it shows the highest percentage (6.7%) of all recorded fractures/dislocations occurred in the hand/wrist area. We presume that the substantial prevalence of impact-contact injuries to the hand and wrist area could be either due to the improper technique employed while catching the ball and/or due to lack of any protective sports equipment such as wicket keeping or batting gloves.

The back/spine area injury prevalence was the second-highest (15.7%) during the 12 year period, but it accounted for the highest percentage (15.6%) of all recorded soft tissue injuries. The study results revealed that the back/spine encounters the highest percentage of non-contact injuries. Non-contact soft tissue injuries to the lower back mostly involve the lumbar muscles and intervertebral discs. Three-year injury surveillance amongst South African provincial age-group cricketers revealed muscle strains (78 injuries) in the lower back were higher than stress fractures (33 injuries) (Stretch, 2003). Also, 55 lumbar injuries were recorded during a six-year observational study amongst Australian first-class cricketers, out of which 41 injuries were soft tissue related, and only 14 were classified as lumbar fractures (Orchard et al., 2002).

Similarly, in our current study, there were 12068 soft tissues injuries, and only 26 fractures/dislocations were recorded for the back/spine area. Unlike the hand injuries, Two-thirds of all back/spine injuries were of a non-contact nature. The causes of non-contact injuries in our study were reported as due to either repetitive movement or strenuous movement. A commonly cited reason for elite cricketers' lumbar injuries is increased playing/training workload. Therefore, the back/spine injuries recorded in the ACC study data may have been a mix of acute and overuse injuries as participants in this study included a nationwide population, the data comprised anyone from a primary school level cricketer to an elite first-class cricketer. Therefore, an acute back/spine injury could have occurred to a recreational cricketer due to improper warmup or to an elite first-class cricketer due to training/bowling workload or vice versa.

Of all the injured body areas, the shoulder area is of particular concern as the highest increase in injury prevalence was observed in the shoulder. Shoulder injury prevalence increased by 86% with 468 injuries occurring in the year 2005 to 864 injuries occurring in 2016. While observing the results presented in Table 3.2, it reveals that the shoulder area was the fifth most commonly injured area during the year 2005 and from the year 2009 onwards, injuries related to the shoulder area have been the third-highest of all cricket-related injuries. Elite cricketers' injury surveillance studies have reported only a shoulder injury prevalence of 0.75% to 1.7% per year (Orchard et al., 2006, Ranson et al., 2013, Frost and Chalmers, 2014) whereas in the current study's 12 year observation period the shoulder area alone accounted for 11.2% prevalence of all cricket-related injuries. The reason behind the low shoulder prevalence rates reported in elite cricket cohorts may be due to the adopted injury definition. Most previous cricket injury surveillance studies record an injury only when a player is unavailable for selection due to an injury. As shoulder injuries in cricket are mostly due to an overuse origin, they may not be recorded during short-term tournament injury surveillances. Hence, the injury definition has to be changed to recording any injury, which requires medical attention irrespective of days missed due to injury.

The injuries recorded in the study were either due to contact or non-contact. The contact injuries were mostly due to collision or impact with an object, ground or person. The non-contact injuries were mainly due to repetitive strenuous movement. Among the injured body areas, the highest prevalence of contact injuries was to the wrist/hand (26.9%) area whereas

the back/spine (31.4%) and shoulder (20.2%) had the highest non-contact injury type. As non-contact injury type was mainly due to repetitive strenuous movement, the back and shoulder should have been injured due to repetitive movement in cricket. The repetitive strenuous movement in the shoulder could have been either fielding throwing or bowling. While bowling requires six balls to be bowled repetitively in each over, throwing occurs infrequently depending on the fielding position. The repetitive strenuous bowling movement may have contributed to the large percentage of non-contact injuries to the shoulder area.

In the current study, information relating to the number of days requiring medical care pertaining to a particular injury could not be obtained; as a result, the severity of the reported injuries could not be established. Among the shoulder injuries, 4768 injuries were of non-contact nature, and 3850 injuries were due to contact with the ground, object or person. The main causes of non-contact injuries were recorded as either due to repetitive movement or strenuous movement. Repetitive shoulder movement in cricket mainly comprises bowling and throwing. Prospective studies conducted amongst elite cricketers suggest that increased throwing workload may be a risk factor for the development of upper limb injury. Fewer rest days and a significant increase in throwing workloads during the week before the injury onset also have been observed as a cause for shoulder injuries (Saw et al., 2011). Shoulder injuries may gradually develop over time before manifesting when the stress loads breach threshold levels (Saw et al., 2011). Another study amongst English cricketers also revealed that 69% of players continued to play with shoulder pain and 75% of shoulder injuries always occurred on the dominant throwing/bowling arm (Ranson and Gregory, 2007), this reveals that most shoulder injuries reported amongst elite cricketers are due to overuse and are related to long term risk exposure.

A total of 8637 shoulder injuries were recorded during the study period of which 7950 injuries (92%) were related to soft tissues, and only 637 (7%) were recorded as fractures /dislocations. As cricket is a non-contact sport, majority of the recorded soft tissue injuries in the ACC data may have been due to overuse related or had a gradual increase in pain and when the stress load breached the pain threshold the individual sought medical attention. Also, the ACC data revealed that 132 injuries were described as due to gradual inflammation of which 103 injuries occurred on the upper limb. Common sports-related non-contact shoulder pain diagnoses often involve conditions such as rotator cuff strain, rotator cuff

tendonitis, sub-acromial bursitis, sub-acromial impingement, labral tears, acromioclavicular ligament sprains and glenohumeral subluxations (Timmons et al., 2012a). All these diagnoses are non-contact injuries in nature and involve the soft tissues surrounding the shoulder joint. Therefore, the majority of the non-contact shoulder injuries in the current study are most likely due to overuse of the shoulder joint's soft tissues.

The data obtained from ACC does not reveal the injury-specific medical diagnosis, which is a limitation to this study. If such information was available, the nature of the reported injuries could be classified as either acute or overuse. The lack of data on "activity at injury onset" is also a limitation to this study, availability of injury onset data would provide insight into whether bowling, batting or fielding was a predominant factor for injury. The same data will also highlight the player position at injury risk. Information related to the injured side was not available in the current study data, if the injured side data were available, it would have been easier to determine the injury predisposition between the dominant and non-dominant sides. Some of the cricket injury data might not have been recorded if the injury was not severe enough to qualify for an injury entitlement claim; also some individuals might not have sought medical care, and this is also a limitation to the current study. One of the main limitations of this study is the lack of player participation data. Higher injury prevalence was likely observed among the age groups of 10-19 year olds as they may be the group which plays cricket on a more regular basis. Therefore this may also mean that participation numbers may be lesser in other age groups in comparison to the 10-19 year olds, and this also may present as a lower injury prevalence rate in those age groups.

3.1.1.6 Conclusion

In conclusion, preventative strategies are required to reduce the nationwide increase in cricket injury incidence. Targeted injury prevention programmes are also needed for teenage cricketers. Non-contact soft tissue injury incidence to the spine and shoulder needs to be addressed as the greatest increase in injury incidence was observed to these two body areas during the 12 year study period.

3.2 Preface to study two

This section of the thesis relates to the second specific aim of the thesis:

To determine what elite cricketers are doing at the time of injury onset

According to van Mechelen, quantification of the extent of a sports injury problem could only be achieved by analysing the results of a sports injury surveillance (van Mechelen et al., 1992). The results of the ACC study revealed the most injured body part, injury type and injury cause. Also, the ACC study revealed that the main cause of non-contact injuries is repetitive and strenuous movement. However, the ACC study does not reveal if the repetitive and strenuous cricket specific movement was either bowling, batting or fielding. To find out what cricketing activity causes the most injuries, injury prevalence of an elite cricketing cohort must be analysed, as only elite cricketers play cricket almost throughout the year, and elite cricketers will mostly train for their specialised playing position.

A first-class fast bowler will repetitively undergo bowling training and frequently bowl in matches almost throughout the year (Saw et al., 2011). This repetitive movement may predispose the fast bowler's body parts to injury. Therefore, to find out what cricket specific activity causes the most injuries, injury surveillance must be conducted on an elite cricketing cohort. While study 1 was aimed at quantifying the prevalence rate across a nationwide cricket playing population, the next study will be specifically focussed to identify the injury-prone cricket playing position. Hence, study 2 was conducted to collect and analyse the injury reports of 14 national cricket squads playing in an international cricket tournament.

3.2.1 Study 2

International cricket injury surveillance: A media-based injury report on the ICC Cricket World Cup 2015

Abstract

Background: Effective injury prevention strategies rely on accurate data from injury surveillance programmes. It was apparent that the Cricket World Cup (CWC) One-Day Tournament in 2015 did not undertake official injury surveillance. Therefore, the aim was to prospectively quantify the number and type of media reported injuries from all CWC competing teams.

Methods: Injury data were collected throughout the 49 tournament matches. The study group monitored the tournament website, official team web pages and major news websites to track availability and injury status of all tournament players (15 members per squad X 14 teams). Captured data included time loss and non-time loss injuries and also recorded the injured player position, injured body part and, activity at injury onset.

Results: The media reported a total of 31 injuries which resulted in players missing a total of 69 matches. Among the tournament players, 23 (12%) experienced time-loss injuries, and of these fast bowlers (12) and batsmen (11) had a similar injury incidence, but fast bowlers missed eight more matches (31) compared to batsmen (23). Location-wise 17, 8 and 6 injuries occurred in the lower limb, trunk and upper limb respectively. More specifically, injuries to the hamstring accounted for the most tournament matches missed (17) followed by the side-strains (15), hand injuries (9), lower back injuries (7) and shoulder injuries (6). Among the 219 players, 4% experienced an injury during bowling, 4% during training and 3% while batting.

Conclusion: Media reported injuries might under-report injuries with teams possibly not wanting to disclose their likely playing team, too far in advance. Nevertheless, this unofficial 2015 CWC data provides a useful addition to previous injury surveillance studies and demonstrates the need for more formal and rigorous injury surveillance programmes. The large proportion (>10%) of injured players, demonstrates the importance of implementing injury prevention practises to maintain a team's overall competitive strength. The current research also offers insights for prioritising injury prevention strategies based on prevalence.

3.2.1.2 Introduction

Irrespective of the sport being played, most athletes are at risk of experiencing either acute or overuse injuries. Sports injuries, while personally devastating for the injured athlete also affects overall team strength. Targeted prevention of sports injuries involves a methodological approach to quantify, identify and analyse injury statistics. Prevention of future sports injuries relies on learning from the analysis of historical sports injuries. Quantification of sports injury prevalence involves systematic injury surveillance.

Effective sports injury surveillance requires the approval of the sporting bodies and event organisers (Newman et al., 2005). It also depends heavily on the quality of injury reporting by the medical staff, coach and players (Ranson et al., 2013). Injury surveillance in cricket is meticulously conducted by several international cricketing boards (Frost and Chalmers, 2014, Orchard et al., 2002, Ranson et al., 2013). Analysis of these injury surveillances and the subsequently published studies have helped understand the extent of cricket injuries and establish their aetiology. In addition to identifying the most injury-prone player position, further analysis helped improve the understanding of the injury mechanism, which predisposes fast bowlers to injury.

Longitudinal studies undertaken on elite Australian male cricketers highlighted the increased injury risk of the fast bowling position (Orchard et al., 2002). A six-year observational study of South African national cricketers concluded that bowling accounted for the majority (40%) of all injuries (Stretch, 2003). Identification of the most injury-prone body areas have been researched, during the years 2014-2016, elite Australian female cricketers reported thigh (14%), wrist (12.8%), knee (11.3%) and shoulder (11%) as the most injured body parts (Perera et al., 2017). Previous research has shown that the most injury-prone body areas are the lower back, shoulder, thigh and knee. These injury findings have been consistently similar across different elite cricket cohorts. Based on these findings, several explanations have been proposed to understand the injury aetiology.

An association between bowling workload and injury has been suggested, with bowlers bowling a total match bowling workload of >50 overs in first-class games and a bowling workload of >30 overs in the second innings have been predicted to have a higher injury risk (McNamara et al., 2017). An extended period of low bowling workloads during Twenty20

matches and unprepared high bowling workloads in first-class matches has also been speculated as an aetiology for injury (Orchard et al., 2015). Prospective cohort studies amongst elite cricketers also suggest that increased throwing workload is a risk factor for the development of upper limb injury (Orchard et al., 2015). Fewer rest days and a significant increase in throwing workloads a week before the injury onset also have been observed as a cause for shoulder injuries (Saw et al., 2011).

Injury surveillance studies have provided various explanations to describe injury prevalence rates, injury-prone positions, most frequently injured body areas and likely injury risk factors. Association between bowling style and lumbar injuries, the correlation between throwing workload and shoulder injuries, the relationship between front foot landing mechanics and knee injuries are some examples of on-going studies exploring injury aetiology in cricket. Such findings help team coaches, medical and sports science staff to design, plan and implement strategies to reduce injury occurrence to their players. Hence, cricket injury surveillance is an essential step toward injury prevention and management.

The International Cricket Council (ICC) is the global governing body for cricket, and they conduct three formats of international championship tournaments, test, One-Day and Twenty20 (ICC Three Game Formats, 2017). To date, the most popular international tournament has been the ICC 50-over cricket world cup (Cricket World Cup Crowd Attendances, 2017). ICC has hosted 20 different national teams, across the eleven editions of the cricket world cup tournament (ICC Cricket World Cup, 2019). Worldwide, the 50-over cricket world cup (CWC) is one of the most viewed international sporting events, with over 2.2 billion watching the most recent tournament (ICC Cricket World Cup, 2017). Despite the 47-year tournament's history and popularity, there has only been a single official injury surveillance study undertaken, during the 2011 CWC (Ranson et al., 2013).

Information provided by ICC administrators verified that there was no official injury surveillance undertaken during the 2015 ICC CWC jointly hosted by Australia and New Zealand. Hence, it would be difficult to obtain injury incidence data from all teams without official permission and team management cooperation. The only way to record the player's injuries during the tournament was to observe what was reported to the media. An injury surveillance study conducted in 2009, among German professional men's football teams, was conducted using media reports released to a sports magazine as no official injury surveillance

was administered (Faude et al., 2009). Another public health study was conducted using media releases from 122 television stations in the United States of America during the years 2002 to 2006 to estimate accidental injury frequency reported to media and to use news media channels to discuss factors for injury prevention, and this study was also conducted due to lack of official accidental injury surveillance records of unnatural accidents (Pribble et al., 2008). Media releases could also be used to estimate the frequency of injury reports and use it as a potential advocacy tool for injury prevention, as a 2011 study conducted in Australia collated all violence and assault-related injury information reported to the media news channels (Stoneham et al., 2013) and suggested preventative strategies should also be reported by the news media channels when injury information is broadcasted.

Therefore based on the methods used in these past media-based injury surveillances, it would be possible to collect injury information relating to the participating squads of the CWC 2015 using official media channels. Reported injuries could then be collated with players missing subsequent matches. Therefore, this study was aimed at obtaining and analysing all media reported injuries during the 2015 ICC CWC.

3.2.1.3 Methods

Study design

Observational descriptive study

Participants

The 2015 ICC CWC took place from 14 February to 29 March 2015. The last date for each playing nation to submit their 15-man squad to the ICC was 7 January 2015, with the exception that some players could be added at a later stage due to injury or for disciplinary reasons. A total of 14 playing nations and 219 players contested the 2015 tournament. Of the 219 players, 47% were specialist batsmen, 46% bowlers and 7% wicket-keepers, with the mean age being 28 ± 4 years (refer to Table 3.5).

Data collection

Data collection commenced from 7 January 2015 till the 49th match on 29 March 2015. Prior to the tournament start, information on each squad for the 14 teams was collected from

several websites (ICC Cricket World Cup, 2019, Check Live Cricket Scores, Match Schedules, News, Cricket Videos Online, 2015, Making cricket even better, CRICHQ, 2015). Player information including, date of birth, batting handedness, bowling arm and predominant playing position were collected and cross-checked between the source websites. The source websites links are provided in the study appendix. All the player positions fast, fast-medium, medium-fast, medium bowlers were grouped and classified as fast bowlers. Injury information was collected from over twenty national and international news websites, and any media reported injuries were cross-checked with source websites. In addition, each match during the ICC CWC 2015 tournament (ICC Cricket World Cup, 2019), was monitored for checking the accuracy of reports relating to players missing matches. Collected injury information included, each injured player's position, injured body area, activity at the time of injury and the number of matches missed due to injury. Screenshots of all the injury-related media reports from all source and media websites are kept for reference and could be provided upon request. The activity at injury onset for two injuries reported prior to the tournament start was unknown, so those two injuries are reported as "prior to tournament" in Table 3.9.

Data analysis

Data were collated using a Microsoft Excel spreadsheet which summarised player descriptive data, tracked injury variables and tournament day availability.

The tournament injury prevalence was calculated as follows:

Sum of all tournament injuries/sum of all tournament players

Injury prevalence per playing position was calculated as follows:

Sum of injuries per playing position/sum of all tournament players

Percentage of injuries per body area, per playing position, was calculated as follows:

Sum of injuries per body area, per playing position/ sum of all tournament injuries

Percentage of injuries per body area was calculated as follows:

Sum of injuries per body area/ total number of injuries

Percentage of matches missed per injured body area was calculated as follows:

Sum of matches missed per body area/sum of tournament matches

Injury prevalence per activity at the time of an injury was calculated as follows:

Sum of injuries per activity/ sum of all tournament players

For the sake of this study, if a player missed a match due to an injury, it was considered a time-loss injury, if there was a media report of a player being injured and if the same player was subsequently recorded playing a match the same day or the next day it was considered a non-time loss injury. The total number of matches missed due to the injury was calculated by summing the first day of any match missed due to the reported injury and the reported unavailability of the same player to play subsequent matches after the injury onset.

3.2.1.4 Results

Of the 219 players, 47% were specialist batsmen, 46% bowlers and 7% wicket-keepers.

Table 3.5. Profiles of players competing in the 2015 ICC Cricket World Cup

Player position	n	%
Right-handed specialist batsman	67	31
Left-handed specialist batsman	37	17
Right fast-medium bowler	22	10
Right medium-fast bowler	20	9
Wicketkeeper	15	7
Right off-break bowler	12	6
Slow left-arm orthodox	11	5
Right fast bowler	9	4
Right leg-break bowler	7	3
Right medium bowler	6	3
Left fast bowler	4	2
Left medium-fast bowler	4	2
Left fast-medium bowler	3	1
Left medium bowler	2	1
Total	219	100

n = number of players

Over the course of the tournament 31 players sustained injuries. Therefore, the tournament injury prevalence was 14%. Between the playing positions, fast bowlers and batsmen, a similar prevalence of time-loss injuries were recorded, as shown in Table 3.6.

Table 3.6. Injury prevalence by playing position

Player position	Time-loss injuries		Non-time-loss injuries		Total injuries	
	n	%	n	%	n	%
Fast bowler	12	5	3	1	15	7
Batsmen	11	5	1	.4	12	5
Spin bowler	3	1	-	-	3	1
Wicketkeeper	1	0.4	-	-	1	0.4
Total	27	12	4	2	31	14 ^a

n = number of injuries, ^a Sum of all injuries (31) / sum of all tournament players (219) = 14%

Overall, fast bowlers had the highest injury prevalence during the course of the tournament. Hamstring strains were much more common among batsmen, but knee and foot injuries were more prevalent among the fast bowlers. No lower back injuries were reported amongst fast bowlers.

Table 3.7. Injured body parts by playing position

Body part	Fast bowler		Batsmen		Spin bowler		Wicketkeeper		Total	
	n	%	n	%	n	%	n	%	n	%
Hamstring	1	3	3	10	1	3	-	-	5	16
Abdominal/side strain	3	10	2	6	-	-	-	-	5	16
Knee	3	10	1	3	-	-	-	-	4	13
Foot	3	10	1	3	-	-	-	-	4	13
Hand	1	3	1	3	1	3	-	-	3	10
Lower back	-	-	2	6	1	3	-	-	3	10
Shoulder	1	3	-	-	-	-	1	3	2	6
Elbow	-	-	1	3	-	-	-	-	1	3
Pelvis	1	3	-	-	-	-	-	-	1	3
Quadriceps	-	-	1	3	-	-	-	-	1	3
Calf	1	3	-	-	-	-	-	-	1	3
Achilles	1	3	-	-	-	-	-	-	1	3
Total	15	48	12	39	3	10	1	3	31	100

n = number of injuries

Of all sustained injuries, hamstring injuries and side strains caused the tournament players to miss the most number of matches.

Table 3.8. Overall matches missed per injured body part

Body part	Total number of injuries for all players per injured body part	Overall matches missed
Hamstring	5	17
Abdominal/side strain	5	15
Knee	4	4
Foot	4	6
Hand	3	9
Lower back	3	7
Shoulder	2	6
Elbow	1	-
Pelvis	1	2
Quadriceps	1	2
Calf	1	1
Achilles	1	-
Total	31	69

Four percent of the tournament players sustained an injury while bowling in matches and three percent while batting in matches. Four percent of players got injured while training but information on whether it was specifically cricket training or gym training was not reported.

Table 3.9. Injury prevalence by activity

Activity	Injuries	
	n	%
Bowling	9	4
Training	9	4
Batting	6	3
Fielding	5	2
Prior to tournament	2	1
Total	31	14 ^a

n = number of injuries

^a sum of all injuries (31) / sum of all tournament players (219) = 14%

During the course of the tournament, fast bowlers missed the highest number of matches (31) due to injuries sustained; this was followed by batsmen missing 23 matches, spin bowlers missing 12 matches and wicket keepers missing 3 matches.

Comparing the number of injuries sustained during the 2015 CWC with the 2011 CWC (Ranson et al., 2013), shows that the number of new time-loss injuries sustained during both the CWC editions were similar.

Table 3.10. Comparison of the injuries between 2011 and 2015 CWC

Injury description	CWC year			
	2011		2015	
	n	%	n	%
Injuries prior to the tournament	23	16	4	13
New time loss injuries	23	16	23	74
New non-time loss injuries	97	68	4	13
Total number of injuries	143	100	31	100

n = number of injuries

3.2.1.5 Discussion

Even in the 2011 CWC injury surveillance study, only 5 of 14 participating national teams agreed to participate (Newman et al., 2005). A conjoined injury surveillance programme initiated by the ICC among the competing nations during the every CWC could help create direction for an evidence-based cricket injury prevention programme. Most of the existing injury surveillance reports have been conducted amongst elite or sub-elite cohorts separately in different countries. There is no platform to compare the injury aetiology of one country's cricket squad to another. When injury surveillance is carried out between competing nations as in the ICC CWC, it will help to determine and compare the actual workload and correlate it with injury incidence. This will also help determine possible aetiology for those injuries and successively help create targeted injury prevention programmes, which could be implemented across all levels of cricket around the world.

As there was no scheduled official injury surveillance during the ICC 2015 CWC tournament, the current study objective was to conduct media-based injury surveillance prospectively during the tournament. Although some players were benched during the tournament,

information regarding the reason for not playing matches was not always available. As all injury data were obtained from media releases, a likely limitation of this study is biased media reporting. Injury information reports for newer players, particularly those from lower-ranked teams may have been considered less newsworthy so injuries to those players may not have been reported on media. Another limitation of the study was the reluctance of some lower-ranked teams to update information on their cricket board websites regarding their players' statistics, injuries and status of their 15 member playing squad ahead of every match, and this means that injuries sustained by players from those squads may not have been available and would not be recorded in this study data.

The percentages of playing positions were similar between players who were predominantly specialist bowlers and batters. As the position, "all-rounder" might not be clearly defined (Orchard et al., 2016b) as to how much percentage of bowling or batting is predominantly done by the player, and as most bowlers get a chance to bat in a 50 over match format, we did not include the all-rounder position in this study. The other positions were clearly defined as the primary position of the player on all source websites. Overall 69 matches were missed by 31 players, the number of injuries reported is the same as the number of players injured, because there was no report of the same player experiencing a second injury.

Among the player positions, fast bowlers missed the highest number of matches due to injuries which is consistent with the 2011 CWC study (Ranson et al., 2013). Relatively, fast bowlers experienced the highest percentage of total injuries and time-loss injuries when compared with other playing positions, as shown in Table 3.6. One of the most recent injury surveillance studies, undertaken amongst elite senior male cricket players during the season 2006-2007 to season 2015-2016 highlighted that batsmen (7%) had the second-highest injury prevalence compared to other positions (Orchard et al., 2016a) similarly in the current study batters (5%) experienced the second-highest injury prevalence and also missed a total of 23 matches.

The hamstring was the most injury-prone body area amongst the current study participants, and this matched the finding of a 6 year, cricket injury surveillance undertaken on elite New Zealand cricketers from 2002/2003 to 2007/2008 seasons; which also identified hamstring strains/tears (11%) as the most common specific diagnosis (Frost and Chalmers, 2014). Detailing injuries by specific diagnosis in the current study, hamstrings (16.1%) and

abdominal side strains (16%) both equally accounted for the highest percentage of injuries recorded, however, hamstrings caused players to miss 17 matches (25%) which was higher than the 15 matches (22%) missed due to abdominal side strains. The hamstring injuries were more commonly experienced by batsmen (10%) when compared to all other playing positions. A similar finding has been reported amongst elite Australian cricketers during 50-over international matches where batsmen had the highest hamstring injury incidence (at 31.3 injuries per 1000 team days) (Orchard et al., 2017).

A proposed explanation for the relatively higher hamstring injury incidence among the elite Australian batters is the size of the cricket field. The logic is that smaller fields do not require as frequent running between the wickets with more runs scored easily through boundaries, whereas larger cricket fields require more running between the wickets. The same study's analysis revealed that compared to international tournaments, matches played in Australia had a higher hamstring injury risk rate (2.3% RR) as the Australian cricket grounds were longer compared to other international cricket grounds (Orchard et al., 2017). During the 2015 CWC, the match-venues were fairly evenly distributed between Australian (53%) and New Zealand (47%) grounds (ICC Cricket world cup, 2017), so it is possible to determine a link between ground size and the relatively larger hamstring injury prevalence of batsmen.

In the current study, fast bowlers (48%) had the highest tournament injury prevalence amongst all playing positions. Majority of the injuries for the fast bowlers occurred on the side of the trunk, knee and foot. Side-strains caused the fast bowlers to miss the most number of matches. Previous studies have reported that side-strain injuries mostly occur on the contralateral side to the bowling arm, with either the internal oblique or the external oblique muscle being mostly affected (Bayne et al., 2011). Side-strains have also been reported to have a recurrence rate of 30% and has been cited as a common risk factor for injury amongst fast bowlers (Nealon and Cook, 2018). Till date, most reports on side-strains have suggested it may be an increased workload-related overuse injury. As the current study was designed as an observational study, we could not conclude on the possibility of workload related aetiology being behind the side-strain prevalence of fast bowlers. Future research could be directed into investigating cricket-related side-strain injuries. While most cricket injury surveillance studies have reported a high lumbar injury prevalence amongst fast bowlers, surprisingly no lower back injuries were reported amongst fast bowlers.

In the current study, as shown in Table 3.9, bowling during matches was one of the most common activities the players were undertaking at the time of injury onset. Of the 69 matches missed due to injuries, fast bowlers missed 31 matches which is the highest proportion among all player positions. While fast bowlers encountered 12 time-loss injuries and missed 31 matches, the batsmen missed 23 matches due to 11 time-loss injuries. Estimating injury severity using time-loss is suggested according to the international injury surveillance consensus (Newman et al., 2005), therefore analysing the results of the study it could be concluded that although the number of time-loss injuries between fast bowlers and batsmen was similar, fast bowlers may have been affected the most due to injuries.

The 2011 CWC study (Ranson et al., 2013), conducted with the cooperation of tournament organisers and medical staff, reported 120 new injuries. Even though the current study's report of 29 new injuries was collected through media reports, all the injury reports were checked across multiple sources before and after a match. Another method used to verify the reported injury was to check if that the player has missed the consecutive match after the injury report. As shown in Table 3.10, a comparison between the 2011 study and the current study reveals that the number of time-loss injuries reported is similar, but as the 2011 study was internally reported, 97 non-time-loss injuries were recorded. This is a limitation in the current study and is reflected in the low number of non-time-loss injuries. If the 2011 study had reports from all 14 competing teams, the percentage 19% (23/120) of new time-loss injuries might have been much higher. As the only source for injury report for the current study was based on the media injury reports which were associated with the matches missed by players, there was a high percentage of 85% (23/27) time-loss injuries recorded. While the results of the current study highlights the most injury-prone position, most injured body part and severity of the injury by the number of matches missed due to the injury, a higher number of injuries and especially non-time loss injuries would have been picked up with prospective longitudinal study supported by the organisers and medical staff of each team.

3.2.1.6 Conclusion: Despite this study design being based on media reports of cricket injuries, this is the only study to our knowledge to report on the injury patterns for the 2015 CWC tournament. This study has reported that fast bowlers were the most injury-prone, hamstrings as the most injured body part and bowling as the most common activity at the

time of an injury. The accuracy of the current study might only be compared with the similarity of the results found among different cricket injury surveillance studies, especially the 2011 CWC cricket study. This study highlighted the number of injuries reported to the media. This study reinforces the appeal made by the international cricket injury surveillance consensus group (Orchard et al., 2016b) to implement effective cricket injury surveillance across cricket playing nations and during major cricket tournaments.

3.3 Preface to study three

This section of the thesis relates to the third specific aim of the thesis:

To determine where and how elite cricketers are getting injured

The first 2 stages of van Mechelen's sports injury prevention model suggests that the sports injury problem must be quantified and the injury aetiology must be identified (van Mechelen et al., 1992). The ACC study quantified the extent of cricket-related injuries amongst the nationwide general population, while the 2015 CWC study quantified the cricket injury prevalence amongst an international elite cricket cohort. While the injury problem was quantified in the ACC study, the specific cricket activity which caused those injuries could not be determined. The findings of the ACC study confirmed that the majority of the cricket injuries were non-contact soft tissue injuries, and the main causes of non-contact injuries were strenuous and repetitive movement. It was hard to ascertain which repetitive movement in cricket was strenuous and caused more injuries. The 2015 CWC study identified that cricket bowling caused the most injuries, and the fast bowler was the most injured.

Thus combining the results of the ACC study and the 2015 CWC study, it could be assumed that fast bowling activity may predispose a cricketer to injury and these injuries could be caused by strenuous and repetitive movement (Saw et al., 2011). This assumption is also confirmed from studies which suggest that the physiological demand is highest for the fast bowler in comparison to all other playing positions (Christie, 2012). Also, several injury surveillance studies have reported a high injury prevalence amongst fast bowlers in comparison to other positions. Based on these findings, the third study was focussed specifically on elite fast bowlers. In order to understand injury aetiology, the medical diagnoses of the most commonly occurring injuries have to be studied. For example, if the most common medical diagnoses for cricket related hand injuries is metacarpal fractures, it could be that those hand injuries occurred due to contact with the ball or the ground. Similarly, if the most common medical diagnoses for sports-related thigh injury was hamstring strain, it may be that a sudden running movement without adequate warmup might be the cause of the injury. Hence, to further explore cricket injuries the third study was conducted amongst elite New Zealand fast bowlers to find out which of their body parts was mostly injured, how those injuries occurred and what was their medical diagnoses.

3.3.1 Study 3.

Quantifying injuries among New Zealand cricket fast bowlers: A 12-month retrospective injury surveillance

Abstract

Background: Effective sports injury prevention relies on comprehensive injury surveillance. Despite the recognition of cricket's fast bowling position as the most injury-prone, there have been only two injury surveillance studies amongst New Zealand cricketers. To help address the lack of research, our study quantified the injury prevalence amongst New Zealand's domestic fast bowlers.

Methods: For the 2017-2018 year, a 12-month retrospective self-reporting electronic injury surveillance was sent to 62 first-class fast bowlers. The surveillance recorded injury type, onset, description, diagnosis, body area and time-loss.

Results: Fifty-six percent (35/62) of the cricketers responded to the injury surveillance, and we found an injury prevalence of 66% with 25 cricketers recording at least one injury. Multiple injuries (47) were reported, with 32 (68%) defined as acute and 15 (32%) as overuse in origin. Half of all acute injuries (16) occurred during bowling, and the most injury-prone areas were the lower back with 9 (19%) injuries, followed by ankles/feet with 7 (15%) injuries, the thighs also with 7(15%) injuries and the shoulders with 6 (13%) injuries. Injuries to the lower back (691 days), ankles/feet (358 days) and knees (304 days) accounted for the highest number of time-loss days from training and/or competing. Of all reported injuries, 15 (32%) were of muscular origin, while 10 (21%) involved bones and 4 (9%) involved damage to ligaments.

Conclusion: Effective injury prevention programmes rely on accurate identification of the most injury-prone body areas. As over two-thirds of injuries occurred in only four body parts, this highlights the pre-emptive value of targeting the lower back, ankles/feet, thighs and shoulders in any subsequent injury prevention programmes.

3.3.1.2 Introduction

Internationally cricket is predominantly played in most Commonwealth nations (Chambers, 2011). The sport has evolved from multiday matches to shorter formats including the hugely popular Twenty20 (T20) format. The commercial success of the T20 format has enabled a large number of cricketers to play these matches more frequently in franchise-based competitions at both home and abroad. Effectively, this has transitioned elite cricket from having a summer season primarily to an almost year-long playing season (Khondker and Robertson, 2018, Soomro et al., 2018). To be considered for selection throughout the year, it is essential that cricketers are consistently playing matches and training year-round (Orchard et al., 2015). The increased physical and physiological demands on modern cricketers have resulted in an increased workload which has been suggested to contribute to increased injury prevalence (Frost and Chalmers, 2014, Orchard et al., 2002, Ranson et al., 2013).

Amongst cricketing positions, the fast bowling position has been repeatedly identified as the most injury-prone (Frost and Chalmers, 2014). Injury surveillance of Australian first-class cricketers highlighted that before 2006 a playing season contained 10-11 limited over games (40-44 days) evenly spaced throughout a six month season; whereas current Australian scheduling requires up to 10 limited over matches played within two months (Orchard et al., 2006). The increased game saturation results in an overall increased workload, especially for fast bowlers, and all other players. Furthermore, changes between game formats require fast bowlers to adapt and bowl only four overs in a T20 match to ~30-40 overs in a first-class multiday match (Orchard et al., 2006). These sudden spikes in workload have been highlighted as the most common predisposing factor for injuries (Olivier et al., 2016a, Ranson and Gregory, 2007).

Fast bowler's predisposition to injury is likely multi-factorial with bowling style, landing biomechanics, increased workload, training mal-adaptations, recurrent injuries and joint anatomy all having been implicated (Arora et al., 2015, Ferdinands et al., 2010, Kountouris, 2017, Olivier et al., 2016b, Orchard et al., 2017, Sharma et al., 2012). With fast bowlers, the lower back, ankle/foot and thigh have been acknowledged as the most injury-prone body areas with only a few studies also highlighting the prevalence of injuries to the shoulder area (Ranson and Gregory, 2007). A mixed bowling action style has been linked to higher lower back injury prevalence (Ferdinands et al., 2010). During the mixed bowling action, the lower

body faces the batsman while the upper body remains in a side-on position (Ferdinands et al., 2010). The rotational and repetitive stresses encountered over time may lead to higher rates of spinal stress fractures (Johnson et al., 2012). Relative to other positions, fast bowlers often retire earlier from first-class cricket which speculatively may be due in part to the lower recovery and higher recurrence rates of spinal stress fractures negatively impacting their career longevity (Bond and Cleaver, 2010). Fast bowler's landing biomechanics and the ground impacts of the metatarsal bones, in particular, have been identified as contributing to stress fractures and soft tissue injuries of the ankle and foot (Olivier et al., 2016b). As fast bowlers are required to run further, and at faster velocities relative to other cricketing positions, it is not surprising that injury surveillance studies reveal thigh injuries have their highest prevalence amongst fast bowlers (Orchard et al., 2017). Although agonist-antagonist muscle asymmetries have been explored as a likely cause of thigh muscular strains, running and bowling workload is implicated as the most common contributor for thigh injuries to the fast bowler (Duhig et al., 2016). This is reflective of the increased prevalence of thigh injuries among fast bowlers after the advent of T20 cricket (Orchard et al., 2015). Fast bowlers are recruited to play in these shorter format matches around the world throughout the year, and the increased workload leads to repetitive strain on the thigh muscles (Dennis et al., 2005).

Soft tissue injuries within the shoulder have previously been shown to be associated with repetitive bowling and decreased rest periods (Ranson and Gregory, 2007). Anatomical changes such as glenohumeral internal rotation deficit (Muraki et al., 2012), posterior shoulder tightness, humeral head retroversion, anterior compartment ligament laxity (Clabbers et al., 2007) and shoulder rotators muscle strength asymmetry have all been identified as common causes of shoulder pain in overhead throwing sports athletes (Mascarin et al., 2017). Despite this, the above injury contributors have not yet been thoroughly investigated and reported for fast bowler's shoulder injuries. While shoulder injury prevalence in cricket has been highlighted in a few injury surveillance reports, unlike spine or thigh injuries, the reported shoulder injury prevalence has been inconsistent amongst published studies. Short-term surveillance during limited over tournaments has reported lower shoulder injury prevalence (0.1% tournament injury prevalence) (Ranson et al., 2013), while long-term surveillance across an entire playing season has revealed a much higher injury prevalence (23%) (Ranson and Gregory, 2007). Most cricket related shoulder injuries

have been attributed due to overuse. Hence, short-term injury surveillances (tournaments) are less likely to record and report shoulder injuries in comparison to the more extended yearly surveillances.

Most commonly, cricket injury prevalence has been calculated based on time-loss injury definitions (Newman et al., 2005), while the inclusion of non-time loss injuries has appeared only in the past ten years (Olivier et al., 2016b). Despite, any injury requiring medical attention and causing match or training loss being considered worthy of recording. Most cricket-related shoulder injuries are of overuse origin (Ranson and Gregory, 2007), and the presentation of shoulder pain severe enough to impact bowling might take weeks or even months to develop. Hence, there may be a reluctance for fast bowlers to seek medical attention at an early stage, and fast bowlers will often continue to bowl during this period with some degree of tolerable pain (Ranson and Gregory, 2007). As most overuse, related shoulder conditions such as subacromial impingement or rotator cuff tendinopathy are associated with anatomical changes like internal-external rotator asymmetry and rotational range of motion deficit, presentation of a shoulder with pain severe enough to impact bowling might have already undergone mild anatomical changes due to repetitive overuse (Bell-Jenje and Gray, 2005). Subjective collection of pain and/or injury data directly from cricketers regardless of time-loss and/or medical attention sought will provide a valuable information source about bowler's shoulders and may aid in better injury prediction and help design injury prevention programmes. Hence, this study's aim was to conduct a 12-month self-reporting retrospective injury surveillance on New Zealand male first-class fast bowlers.

3.3.1.3 Methods

Study design

Observational descriptive study

Participants

New Zealand's six major cricket associations and New Zealand Cricket's high-performance centre management provided written informed consent for the injury data collection. Lists of their first-class fast bowlers contracted to play during the year 2017-2018 were provided to the researchers. All invited participants were male cricketers aged 18 and above. Unfortunately, female cricketers were not included as informed consent was not given by

their team management. The University of Canterbury ethics committee approved the study (HEC 2016/74/LR-PS).

Data collection

A total of 62 fast bowlers were invited to participate in the injury surveillance, and the individual's voluntary consent was obtained before partaking in the injury surveillance. An electronic self-reporting injury surveillance system was created by the research team using Qualtrics, LLC USA, which enabled participants to record their injuries using their smartphones or devices. The injury surveillance design also allowed the participants to record, save and submit multiple injuries. The participants were informed to record their injuries even if medical attention was not sought.

Injury survey questions

A total of 35 questions were included in the survey. The survey was split into four sections, and the first section questioned participants' anthropometry, bowling speed, identified bowling arm, and bowling action. The second section sought information on average training hours per week, hours per session and the number of rest days/week. In the subsequent sections, participants were able to record their injury type, injured body part, injured side, provide an injury description and identify the activity at the onset of injury, the situation of injury, any medical diagnosis and the days missed due to injury and any injury recurrence. All the survey questions are provided in the appendix.

Injury definitions

All injuries could be recorded as either an acute or overuse injury, and the participants were informed to record each injury separately based on the following definitions,

Acute injury: An acute injury is any injury which occurred suddenly or accidentally. It may or may not have interrupted your training session or your match. An acute injury is also any physical injury that has kept you away from at least a single training session or match. It may or may not have resulted in physiotherapist or doctor's care (Ristolainen et al., 2010).

Overuse injury: Overuse injury is any injury which has caused you pain or is causing you pain during bowling, batting, fielding or anytime during the match, training or during exercise workouts. This injury might not have any noticeable external cause of injury. This

injury could have gradually caused worsening pain during or after bowling, in matches, training or exercise. The pain would have become worse when loading is continued or may stop you from exercising completely (Ristolainen et al., 2010).

Recurrent injury: *A recurrent injury is an injury occurring on the same body side, and body part reported as the same injury earlier in the same season, but which had recovered.* (Ristolainen et al., 2010).

Data Analysis

Participant's data were analysed using Microsoft Excel descriptive statistical functions. All injuries were presented as descriptive data. The injury prevalence was expressed as a percentage, and it was calculated as the total number of reported injuries divided by the number of participants. All reported injuries will be presented descriptively as injury prevalence because to calculate injury incidence playing and training exposure has to be collected, for this study the playing exposure data will not be collected due to the self-reporting subjective data collection method.

3.3.1.4 Results

From the 62 cricketers surveyed, only 35 (56%) responded to the injury surveillance invitation and their anthropometric data is provided in Table 3.11. During the 12 month study period 25 (71%), cricketers reported multiple injuries (giving 47 total injuries). In total, 32 (68%) injuries were identified as acute with 15 (32%) recorded as overuse injuries. Amongst the 35 cricketers, 23 (66%) reported one acute injury, while 8 (23%) reported two acute injuries and one cricketer experienced three acute injuries. During the same time, 12 (35%) cricketers reported one overuse injury and 3 (9%) cricketers reported two overuse injuries.

Table 3.11. Anthropometric and demographic data (mean \pm range) n= 35

Weight (kg)	Height (m)	Age (years)	Arm dominance Right/left
87 \pm 9	1.86 \pm 0.06	26 \pm 4	29/6

The lower back (9 injuries) was reported as the most injury prevalent area, with 19% of all reported injuries occurring in this region. The lower back injuries also caused cricketers to miss 30% (691 days) of their total playing days. While the ankle/foot (7 injuries) and thigh (7 injuries) areas both experienced a 15 % injury prevalence. Interestingly, the ankle/foot

injuries caused cricketers to miss 358 days, a figure more than thrice as high as the number of days missed due to thigh injuries (107 days). Despite, the shoulder area experiencing the fourth-highest injury prevalence at 13%, (6 injuries) it only resulted in cricketers missing five playing days (0.2%) as shown in Table 3.12. Of note, all reported shoulder injuries were on the player's dominant bowling/throwing shoulder. A total of 2330 days were missed by the 25 injured cricketers, which averages to 93.2 days missed per injured bowler per year.

Table 3.12. Injury prevalence and missed days by body area

Body area	Acute injuries		Overuse injuries		Total injuries		Days missed	
	n	(%)	n	(%)	n	(%)	n	(%)
Lower back	5	11	4	9	9	19	691	30
Ankle/foot	6	13	1	2	7	15	358	15
Thigh	5	11	2	4	7	15	107	5
Shoulder	4	9	2	4	6	13	5	0.2
Hand	4	9	0	0	4	9	141	6
Hip	2	4	0	0	2	4	130	6
Knee	2	4	0	0	2	4	304	13
Abdomen	1	2	1	2	2	4	240	10
Side of trunk	1	2	1	2	2	4	64	3
Shin	0	0	2	4	2	4	130	6
Groin	1	2	0	0	1	2	21	0.9
Calf	1	2	0	0	1	2	3	0.1
Elbow	0	0	1	2	1	2	0	0
Neck	0	0	1	2	1	2	16	0.9
Total	32	68	15	32	47	100	2330	100

n = number of injuries

Thirteen (41%) of the experienced acute injuries reoccurred at the same body area. Specifically, the lower back and ankle/foot had 3 (23%) re-occurring injuries, while both the shoulder and thigh 2 (15%) recurrent injuries. The hip, knee and wrist/hand each experienced one recurrent injury. The most common activity during the onset of an acute injury was bowling (16 injuries) followed by fielding (7 injuries) as shown in Table 3.13. Fifty-one percent of all acute injuries were experienced during matches, while only 17% were reported to occur during team training sessions. Bowling in matches and fielding during team training sessions jointly accounted for all four acute shoulder injuries.

Table 3.13. Activity during acute injury onset

Activity	n	(%)
Bowling	16	50
Fielding	7	22
Other activity	5	16
Batting	4	13
Total	32	100

n = number of injuries

The most commonly injured tissues were related to muscle strain/tears/inflammation with 15 injuries (32%). This was followed by ten bone fractures (21%) and four ligament sprains/rupture/tears (9%). The five stress fractures of the lower back (11%) accounted for the highest percentage of injury diagnosis by specific body part, and this was equally followed by four hamstring strains (9%) and four rotator cuff pathology (9%) as shown in Table 3.14.

Table 3.14. Medical diagnoses for the reported injuries

Injury diagnoses	n	(%)
Lower back stress fracture	5	11
Hamstring strain	4	9
Rotator cuff inflammation	4	9
Osteitis pubis	3	6
Ankle impingement	3	6
Lumbar disk prolapse	2	4
Metacarpal fracture	2	4
Subacromial impingement	2	4
Anterior cruciate ligament rupture	1	2
Medial collateral ligament injury	1	2
Tennis elbow	1	2
Cervical disc prolapse	1	2
Medial sesamoid ligament tear	1	2
Jones fracture	1	2
Achilles tendon strain	1	2
Quadriceps strain	1	2
Hip flexor strain	1	2
Hernia	1	2
Rib impingement	1	2
Shin stress fracture	1	2
Shin splints	1	2
Calf muscle tear	1	2
Groin muscle tear	1	2
Thigh muscle tear	1	2
Trunk side muscle strain	1	2
Hand web split	1	2
Unknown hand ligament tear	1	2
Unknown ankle fracture	1	2
Unknown lower back muscle soreness	1	2
Unknown lower back pain	1	2
Total	47	100

n = number of injuries

3.3.1.5 Discussion

Although injury surveillance of elite cricketers has been successfully implemented across most international cricketing boards, the last scientifically published injury surveillance report of New Zealand cricketers was more than a decade ago in 2008 (Frost and Chalmers, 2014). Our current study provides a detailed description of the injuries sustained during 12 months by an elite cohort of cricket fast bowlers in New Zealand. Despite having a 56%

injury surveillance response rate, the obtained data offers a rich descriptive summary of the most injured body areas, the injury descriptions, prevalence and diagnoses. That said, while players were encouraged to undertake the injury surveillance even if they had not experienced any injury, the likelihood that players who did experience injuries undertaking the injury surveillance may have been higher, which itself may have influenced the injury prevalence observed in these results.

In the current study, injuries to the lower limb, lower back and shoulders had the highest injury prevalence, with the lower back experiencing the highest percentage of all injuries sustained. Lower back injuries also caused the fast bowlers in the current study to miss more than a quarter of the total training and match days. In comparison, during the 2011 ICC cricket world cup, cricketers missed 22 days (0.7 % tournament injury prevalence) due to lumbar injuries (Ranson et al., 2013), but in the 2015 ICC cricket world cup, there were no reported incidences of lumbar injury. This may also have been due to the nature of the ICC 2015 CWC study where all injuries were collected using media reports, and the majority of them were time-loss injuries, as most lumbar injuries are due to overuse. From the several aetiologies proposed for fast bowlers' lower back injuries, repeated lumbar rotation and lateral flexion during the delivery stride has been identified as a high-risk causative factor (Ferdinands et al., 2010). In the lower back area, the L4 and L5 vertebrae are susceptible to a higher injury rate, and this may be due to their anatomical proximity to the pelvis. During every bowling delivery, the L4 and L5 vertebrae are subjected to flexion, extension and rotation over the relatively stable pelvis (Kountouris, 2017). This repeated lumbar vertebral movement over the pelvic joints may pre-dispose the lumbar soft tissues to overuse injury. Also, during the front foot landing phase, the impact of the bowler's body weight and the high ground reaction forces encountered by the lumbar vertebrae might cause degenerative changes to it. In the current study, 4% of players reported lumbar disk prolapse and 11% reported lower back stress fracture. Following a lumbar injury, a minimum recovery period of 90-120 days is recommended with some athletes taking up to a whole year to recover (Huang et al., 2016). As these lower back injuries present a chronic condition, taking longer recovery times might explain the high percentage of days missed by the fast bowlers in the current study.

The 15% ankle/foot injury prevalence of the current study is similar to previous injury surveillance reports of Australian and New Zealand first-class cricketers (Frost and Chalmers, 2014, Orchard et al., 2002, Ranson et al., 2013). In the current study, the cricketers reported a 6% ankle impingement diagnoses. While the exact impingement condition is not reported, posterior ankle impingement has been identified as a major cause of ankle pain among cricketers due to repeated landing on the back foot during the delivery stride (Mansingh, 2011). Sesamoid ligament tear and fractures have also been reported, with ground hardness, repetitive impacts and increased bowling workload all identified as aetiologies for ankle injuries (Spratford and Hicks, 2014). As fracture and impingement related pain could be easily aggravated due to impact while bowling, the cricketers might have taken more extended recovery periods, this may help to explain the 15% days missed (N= 358) due to ankle/foot injuries.

Since 2006, an increase in thigh injuries has been consistently reported amongst international elite cricket cohorts (Orchard et al., 2017). In the current study, there was a 15% thigh injury prevalence, with a specific 9% hamstring strain prevalence. Since the year 2006, hamstring injury incidence has been reported to increase, especially after the prominence of T20 cricket (Orchard et al., 2017). In the current study, cricketers reported a 15% recurrence of thigh injuries, and research reveals that there is a 3.7 times increased risk for thigh injuries amongst players with a previous history of thigh injury (Orchard et al., 2015). Sudden spikes of bowling workloads amongst elite cricketers have been postulated to contribute to thigh injuries (Gabbett, 2016). As the current study cohort consisted of elite cricketers, some of whom also played different cricket formats internationally, there is the possibility that injuries may be due to a sudden increase in bowling volume. Most reported thigh injuries are muscle-tendon related strains and, these soft-tissue injuries recover faster in comparison to hard tissue injuries leading to an earlier return to play (Jacobsen et al., 2016). This might explain the low percentage of days missed due to thigh injuries amongst the current study participants.

Shoulder injury onset amongst cricketers is either acute or overuse. Acute shoulder injury onset can be either due to direct impacts with the ground while fielding or while running batting (diving when running between the wickets). While the cause for acute shoulder injury onset is mostly due to direct impact, in contrast, overuse related shoulder injury is more likely

to be multifactorial. Overuse related shoulder pain is mostly associated with either repetitive throwing or bowling. Bowling and throwing workload spikes have been repeatedly identified as a risk factor for overuse shoulder injuries (Bell-Jenje and Gray, 2005). Shoulder injury incidences of 5.5% amongst English county cricketers (Ranson and Gregory, 2007) and 7% amongst Australian first-class cricketers (Orchard et al., 2006) have been published, both of these reports also suggested an association between bowling workload and injury (McNamara et al., 2017).

Repetitive bowling and fielding-throwing might cause tightening of the posterior shoulder joint capsule while stretching its anterior aspect (Wolf et al., 2009). As glenohumeral rotation is elicited by the rotator cuff muscle, repetitive overload could weaken and strain the muscle. The weakening of the rotator cuff muscle strength could in-turn affect glenohumeral instability (Murakami et al., 2018). These adaptations can also be associated with humeral head translation, labral pathology and sub-acromial impingement (Mountjoy et al., 2015). In the current study, some of these conditions were reported by the cricketers, who reported a 13% shoulder injury prevalence. The shoulder area injuries involved the rotator cuff and subacromial space, as shown in Table 3.14. Shoulder injuries among other overhead throwing sports athletes have been associated with factors such as altered shoulder rotation range of motion, muscle strength ratio, posterior shoulder tightness, increased training workload and altered scapular kinematics (Cook et al., 1987, Hurd et al., 2011, Johnson, 1992). Repeated internal rotation and shoulder circumduction with low rest periods have been proposed to cause structural adaptations to the shoulder joint (Wymore and Fronek, 2015). Detrimental effects on the rotator cuff tendon and joint capsule due to higher training workload have also been proposed as possible shoulder pain aetiology (Sein et al., 2010).

The repetitive glenohumeral rotation and circumduction movement executed by elite bowlers may also cause changes to the shoulder's soft tissues. While it is still unclear whether overuse related structural changes lead to an injury or vice versa, periodic shoulder screening may help associate the anatomical changes to shoulder injury incidence. Hence, regular assessment of shoulder range of motion, internal-external rotator muscle strength ratio, posterior shoulder tightness and scapula-humeral rhythm throughout the playing season will help monitor and potentially help to identify cricketers at risk of a chronic shoulder injury.

The results of the current study could be influenced by the data collection method. The retrospective data collection method was implemented to collect data directly from the players with a new injury definition in which any experienced musculoskeletal pain could be reported as an injury and not just injuries which caused matches to be missed. However, we acknowledge that retrospective surveys may not accurately report injury prevalence as it relies on the participant's response and lacks the physician's verification. We acknowledge that retrospective injury surveillance methods could also have recall bias, where some injury information could have been lost due to failure to recall the injury event, and also the tendency to over-report the severity of the past injuries with respect to the days missed due to an injury (Harel et al., 1994).

In conclusion, the current study has provided an insight into the overall injury prevalence amongst elite New Zealand fast bowlers, and it has also provided body-part-specific injury diagnosis. While injuries to cricketers' lumbar, thigh and foot area have been well discussed and reported, there is still a paucity of literature for cricket-related shoulder injuries. The study results provide separate acute and overuse related injury information and specific injury diagnoses, which will provide valuable evidence to future research aimed at exploring cricketers injuries.

3.3.1.6 Conclusion

In the current study, we identified the lower back, thigh, ankle and shoulder as the most injury-prone body areas amongst a cohort of elite cricket fast bowlers and also observed that the rotator cuff muscle was predisposed to injuries in the shoulder area. While the cause for lumbar, thigh and ankle injuries are well documented, uncertainty still exists regarding the factors predisposing cricket-related overuse shoulder injuries. However, we recommend regular musculoskeletal screening of competitive cricket bowlers, so that the structural changes occurring in the shoulder due to repetitive rotation could be monitored, which may help reduce injury incidence.

3.4 Preface to study four

This section of the thesis relates to the fourth specific aim of the thesis:

To determine the differences in shoulder joint's range of motion and muscle strength between injured and uninjured fast bowlers

The analysis of the ACC study revealed that the shoulder area experienced the highest increase in injury incidence over the 12 years. Along with that, it was also found that the majority of the injuries to the shoulder were non-contact injuries, and the ACC study non-contact injuries were classified as due to strenuous and repetitive movement. While the cricket specific activity which caused all those injuries could not be identified, the 2015 CWC study was conducted to quantify elite cricket injuries. The results of the study revealed that bowling was the activity, most reported to cause injury onset, and the fast bowling position was the most injury-prone.

Hence, the third study was focussed only on elite New Zealand fast bowlers. This study highlighted that the shoulder was one of the most injured body areas and the reported shoulder injuries involve the rotator cuff muscles and subacromial space. The first 2 stages of van Mechelen's sports injury prevention model suggests that the sports injury problem must be quantified and the injury aetiology must be identified (van Mechelen et al., 1992). The first three studies of the thesis, quantified shoulder injury prevalence amongst both elite cricketers and the general population. Also to understand the shoulder injury aetiology, combining the results of the first three studies it is suggested that the shoulder mostly experiences non-contact soft tissue injuries due to bowling and it is reassured by the elite fast bowlers who reported rotator cuff pathology and subacromial impingement as the principal diagnoses of their shoulder pain (Manske and Ellenbecker, 2013).

While study 1 quantified shoulder injury prevalence across all levels of cricket, study 2 explored the most injury-prone playing position as this information could not be obtained from the first study. Furthermore using the results of study 2, it was identified that the fast bowler was the most injury-prone playing position, hence study 3 was focussed on finding out which body parts were injury prone amongst fast bowlers. The findings of study 1, 2 and 3 were reviewed with existing shoulder injury literature.

Literature review suggests that rotator cuff pathology and subacromial impingement conditions are interrelated. Research also suggests deficits in the rotational range of motion and rotator cuff muscle strength may be precursors or an outcome of shoulder overuse. Hence, study 4 was conducted to assess the glenohumeral rotational range of motion and isometric muscle strength of shoulder rotators between injured and uninjured fast bowlers.

3.4.1 Study 4:

Comparison of shoulder muscle strength and range of motion between fast bowlers with and without shoulder injuries

Abstract

Background: Bowling and throwing overload in cricket affects the glenohumeral joint's (GH) dynamic and static stabilisers and disrupts its function. Range of motion (ROM) and isometric muscle strength (IMS) assessments help in identifying a cricketer's shoulder joint injury risk. Hence, to investigate training-related anatomical changes, the shoulders of cricket fast bowlers were assessed.

Methods: At the end of the 2018 New Zealand cricket season 26 male club-level fast bowlers were recruited. Objective screening of shoulder rotators IMS and GH rotational ROM was undertaken, while any reporting of shoulder pain was also noted. Bowlers, who complained of pain during objective testing for shoulder pain were considered injured for this study.

Results: Overall, among the 26 fast bowlers (24.2 ± 5.7 y, mass 82.3 ± 8.4 kg, height 1.84 ± 0.09 m), nine (35%) fast bowlers had shoulder pain during the screening, but only in their dominant shoulders. Bowlers with shoulder pain had non-significantly slightly lower ROM on their dominant shoulders than their uninjured counterparts, IR ROM, (injured; $76 \pm 8^\circ$, uninjured $79 \pm 9^\circ$, $P < 0.44$), and ER ROM (injured; 81 ± 12 , uninjured $86 \pm 5^\circ$, $P < 0.25$). Isometric muscle strength of the shoulder rotators was similar between the injured and uninjured bowlers. Regardless of shoulder pain, all bowlers exhibited a trend of slightly weaker external rotators compared to their internal rotators (dominant IR, 42 ± 8 N.m; dominant ER 39 ± 6 N.m; non-dominant IR, 40 ± 6 N.m; non-dominant ER 39 ± 7 N.m).

Conclusion: Weaker external rotators have been associated with humeral superior-anterior translation and compression of the subacromial space tissues, and subacromial space pathology is the most common overuse related shoulder injury. Hence, regular assessment of shoulder ROM and IMS will help detect any anatomical changes and enable preventative steps to strengthen the weaker shoulder-rotators and increase ROM.

3.4.1.2 Introduction

Cricket injury surveillance studies have highlighted the increase in injury incidence from the year 2006 till now (Orchard et al., 2016a). Also, the fast bowling position has been identified as the most injury-prone (Gregory et al., 2004a) in comparison to other cricketing positions. Injuries such as lumbar disc herniation, hamstring strains, trunk side strains and shoulder impingement syndromes have been emphasised as commonly reported injury diagnoses amongst fast bowlers (Hulin et al., 2013, Kountouris, 2017). While exploring the cause of injuries, it has been identified that most cricket-related shoulder injuries are of gradual onset and overuse origin (Bell-Jenje and Gray, 2005, Cowderoy et al., 2009). Shoulder injury incidence amongst fast bowlers has been commonly reported, yet very few studies have explored the pathomechanisms of cricket-related shoulder injuries.

To better understand the pathomechanism of cricket-related shoulder overuse injuries, it is prudent to review commonly reported shoulder conditions amongst other overhead throwing athletes. Shoulder overuse conditions such as subacromial impingement, subacromial bursitis, rotator cuff tendinopathy and labral tears are all frequently reported amongst overhead throwing sports athletes (Waldman, 2016, Andersson et al., 2017). Subacromial space pathology is often interrelated to other shoulder conditions. Impingement of the rotator cuff muscles against the acromion process causes inflammation, this inflammation leads to tendonitis and tendonitis causes oedema, and this may lead to further subacromial space reduction (Brossmann et al., 1996). It is debated whether a reduction in subacromial space causes inflammation of the muscle or vice versa. Shoulder injury studies have explored the role of the rotator cuff muscle strength in subacromial space reduction (Page, 2011), as rotator cuff muscle strength directly affects the available glenohumeral (GH) rotational ROM (Rosa et al., 2018). Rotator cuff fatigue, weakness or strain will affect GH active ROM. Pain-free GH joint rotation is critical to executing the fast bowling cricket action.

The GH joint external rotation of 90-110° and internal rotation of 70-80° is considered indicative of normal ROM without restrictions (Charles and A, 2009). The available GH ROM is dependent on the strength of the muscles and laxity of the ligaments supporting the joint. The rotator cuff muscles act as the dynamic stabilisers while the glenohumeral ligaments act as the static stabilisers (Berckmans et al., 2017). Long term bowling and throwing workload combined with low recovery periods can cause adaptive changes to the

joint's stabilisers and affect ROM (Beitzel et al., 2016). Ligament laxity and muscle tightness negatively affect the GH joint ROM. Pectoralis minor muscle tightness causes internal rotation gain, and tightness of the posterior shoulder capsule causes internal rotation deficit (Worthington, 2010). Increased ER and decreased IR has been observed as an anatomical adaptation on the dominant shoulders of professional athletes who play overhead throwing sports (Scher et al., 2010). Compared to other baseball playing positions, the pitchers are required to frequently throw, and it is thought that this frequent action results in anatomical adaptations leading to a reduction in shoulder internal rotation (Hurd et al., 2011). Similarly, if shoulder ROM is assessed between different cricketing positions, it may also reveal the presence of structural adaptations due to the specific demands of the playing position.

Structural adaptations of the glenohumeral joint initially occur to the soft tissues surrounding it. During every ball delivery, the shoulder has to undergo abduction and rotation. Shoulder rotation is primarily elicited by the rotator cuff muscles. Glenohumeral rotation is dependent on the force created by the muscles surrounding it. The rotator cuff muscles comprising of supraspinatus, infraspinatus, teres minor and subscapularis (SITS) muscles stabilise the humeral head within the glenoid cavity and rotate it during rotational movements (Alpert et al., 2000). The eccentric activity of the external rotator muscles and the concentric activity of the internal rotator muscles perform the internal rotation (Boileau et al., 2014). The concentric activity of the external rotators and eccentric activity of the internal rotators causes external rotation, commonly used during the cocking phase in cricket fielding throwing and bowling (Niederbracht et al., 2008). Among overhead throwing sports athletes, internal rotator muscles have been identified to be significantly stronger than the external rotators.

The frequency of the throwing action and intensity of the stimulus strengthens the internal rotators (Laver et al., 2018). The dominant arm is more heavily involved when executing cricket bowling and throwing during fielding. Therefore, ROM and muscle strength differences between the dominant (D) and the non-dominant (ND) arms are likely to exist. Lower internal rotation ROM on the dominant shoulders have been reported amongst handball and baseball players (Bayios et al., 2001, Vodička et al., 2018). The asymmetry between the internal and external rotators has been associated with shoulder injuries (Wang and Cochrane, 2001). Stronger internal rotators and weaker external rotators have been

proposed to cause the superior-anterior movement of the humeral head (Niederbracht et al., 2008). The superior-anterior movement reduces the subacromial space and causes friction between the acromion process and rotator cuff tendons. The subacromial bursa is also present in the subacromial space, so narrowing of the space has been proposed to cause inflammation in the bursa (Timmons et al., 2012a). Hence, early detection of such muscular adaptations in the shoulder joint will help practitioners take preventative strategies and may help reduce shoulder overuse injury incidence. Muscle strength asymmetries can be assessed by measuring the isometric muscle strength of the internal and external rotators. It is proposed that this assessment may help identify fast bowlers susceptible to overuse shoulder injuries.

Structural adaptations of the shoulder due to frequent bowling and throwing could also affect the shoulder joint capsule (Borsa et al., 2008). The GH joint capsule is a fibrous capsule, surrounding the GH joint, extending from the glenoid labrum to the humeral neck (Andary and Petersen, 2002). It is fused with the rotator cuff tendons and is reinforced by the GH ligaments. High bowling workload involves repetitive GH joint rotations (Whiteley and Oceguera, 2016). This repetitive rotation stretches the anterior capsule during the cocking-throwing phase and also tightens the posterior part of the joint capsule (Whiteley and Oceguera, 2016). A posterior joint capsule is associated with internal rotation deficit on the throwing side amongst baseball players (Keller et al., 2018). Posterior shoulder tightness is associated with shortening of the posterior dynamic stabilisers and causes shoulder pain (Page, 2011). The tightness of the posterior dynamic stabilisers may cause superior-anterior translation of the humerus leading to the reduction in the subacromial space (Waldman, 2016). The reduction in subacromial space can lead to impingement syndrome, which has been observed amongst athletes with posterior shoulder tightness (Page, 2011). The tightness of the posterior dynamic stabilisers has also been shown to cause a deficit in the GH joint internal rotation (Keller et al., 2018). A deficit in the rotational ROM will impact bowling and throwing actions.

Most of the throwing related shoulder injury studies have been amongst baseball cohorts, yet cricket bowling and throwing involves similar shoulder movement dynamics. Hence, it is logical that, if cricketers' shoulders were assessed using the same method, it would identify the presence of any structural adaptations occurring in the joint due to the demands of the sport. The measurement of ROM and muscle strength is critical to assess any functional

restrictions present in a joint. Therefore, the objective of this study was to observe ROM, IMS and posterior shoulder tightness and assess differences between the dominant and non-dominant shoulders as well as between injured dominant and uninjured shoulders.

3.4.1.3 Methods

Study design

Observational cohort study

Participants

The participants had to be above 18 years of age at the time of the study and have predominantly played as a fast bowlers for least for five years. The University of Canterbury ethics committee approved the study (HEC 2017/55/LR-PS).

Procedures

The cricket club managers were informed about the study, and their consent was obtained before advertising the study in their clubs. Senior club level cricketers were recruited for this study through voluntary participation. All volunteering participants were objectively tested for shoulder pain using Hawkins, Jobe's, Neer's and the Painful Arc diagnostic tests (Hawkins and Kennedy, 1980, Gillooly et al., 2010, MacDonald et al., 2000, Çalış et al., 2000). The participants indicated the level of pain elicited during the tests on a visual analogue scale. All participants were asked to subjectively report shoulder pain history on an injury history form. Bowlers, who complained of pain during the objective testing were considered injured, and bowlers without any shoulder pain were considered uninjured for this study.

Instruments

Resisted manual muscle testing was undertaken using the Microfet 3 (Hoggan Scientific, LLC, Salt Lake City, UT, USA) handheld muscle testing dynamometer (HHD) which has been validated with moderate to excellent intra-tester reliability (ICC 0.56-0.92) (Clarke et al., 2011). A goniometer (EGM-422-EMI 12" Elite medical instruments, Fullerton, CA, USA) was used to measure ROM.

Isometric muscle strength and range of motion testing

All tests were measured bilaterally with participants in a supine decubitus position on an elevated plinth. An HHD was used to measure isometric muscle strength. Participants were familiarised with isometric contractions and were instructed to perform internal or external rotation against the resisted HHD. The HHD was positioned in place by the tester, and the participants were asked to build up force for 5 seconds against it. Triplicate measures were performed with the mean used for the data analysis.

Specifically, the isometric muscle strength was evaluated with the shoulder in 30° shoulder abduction and 90° elbow flexion (Donatelli et al., 2000). Resisted external rotator isometric muscle strength was measured with the HHD positioned 2cm from the styloid process of the radius on the dorsal side of the forearm. The internal rotator isometric muscle strength was measured with the HHD positioned 2cm from the proximal wrist crease on the ventral side of the forearm.

A goniometer was used for measuring the range of motion and posterior shoulder tightness. Using the olecranon process as the axis point the goniometer's moving arm was moved with the forearm, while the goniometer's fixed arm was placed parallel to the plinth. A towel was folded and placed as a wedge between the surface of the scapula and plinth for stability. Shoulder internal and external active range of motion was measured with the tested side in 90° glenohumeral abduction and 90° elbow flexion (Muir et al., 2010).

Posterior shoulder tightness was measured with the shoulder at 90° abduction and elbow at 90° flexion (Myers et al., 2006b). The acromioclavicular joint was used as the goniometer's axis, the fixed arm was parallel to the plinth, and the moving arm was in-line with the lateral epicondyle. Passive horizontal adduction was performed towards the mid-line, and the goniometer reading was recorded. A towel was folded and placed as a wedge between the surface of the scapula and plinth for stability. Resisted isometric muscle strength, rotational range of motion and posterior shoulder tightness were measured thrice, and the average of three readings was recorded.

Reproducibility

To assess intrarater reliability, 11 participants ($N=11$, age 24 ± 5 y, mass 81 ± 8 kg, height 1.83 ± 0.11 m) were measured twice with seven days separating assessments. The Intra-class correlation coefficient (ICC) scores for the two trials were, ROM, ICC = 0.94 (95% CI: 0.84-0.98); IMS, ICC = 0.88 (95% CI: 0.71-0.96) and PST, ICC was 0.82 (95% CI: 0.60-0.94).

Statistical analysis

Two-tailed independent samples T-Tests were used to compare differences between the injured and uninjured fast bowlers. All data were assessed for statistical significance at $P < 0.05$ level of significance. Furthermore, to demonstrate magnitudes of effects, Cohen's delta (d) was used to determine the effect size of the differences between the injured and uninjured fast bowlers. Effect sizes were classified as trivial if $d \leq 0.2$, small if $d = 0.2 - 0.6$, moderate if $d = 0.6 - 1.2$, large if $d = 1.2 - 2.0$ and very large if $d = 2.0 - 4.0$.

3.4.1.4 Results

During the 2018 cricket season, 26 male club level fast bowlers (24 ± 5 y, mass 82.3 ± 8.4 kg, height 1.84 ± 0.09 m) volunteered for this study. Study participants had a mean cricket playing experience of 7 ± 3 years at a senior club level, and their descriptive data is shown in Table 3.15. A total of nine (35%) participants subjectively reported the presence of shoulder pain and also complained of shoulder pain during the objective tests on their dominant bowling shoulders. The injured bowlers reported a moderate level of shoulder pain (46.6 ± 15) on a visual analogue pain scale and reported experiencing the shoulder pain for an average duration of 8 ± 2 months. Bowlers with shoulder pain exhibited a slightly lower ROM in comparison to their uninjured counterparts. Isometric muscle strength of the shoulder rotators was similar between the injured and uninjured bowlers. Regardless of shoulder pain, all the bowlers exhibited slightly weaker external rotators than the internal rotators on the dominant shoulders. There was a slightly higher posterior shoulder tightness on the dominant shoulders in comparison to the non-dominant side, as shown in Table 3.16.

Table 3.15. Participant descriptive data (mean \pm range)

Number of participants = 26	
Age (years)	24.2 \pm 5.7
Weight (kg)	82.3 \pm 8.4
Height (m)	1.84 \pm 0.09
Dominant arm	19 Right / 7 Left

Table 3.16. Differences of ROM, IMS and posterior shoulder tightness (mean \pm range)

			Injured (n= 9)	Uninjured (n= 17)	p-value ^a	Cohen's <i>d</i> ^b
Range of motion (°)	IR	Dominant	76 \pm 8	79 \pm 9	0.44	0.35 ^s
		Non-dominant	78 \pm 12	76 \pm 10	0.77	0.18 ^t
	ER	Dominant	81 \pm 12	86 \pm 5	0.25	0.55 ^s
		Non-dominant	79 \pm 14	85 \pm 6	0.27	0.54 ^s
Isometric muscle strength (N.m)	IR	Dominant	42 \pm 9	43 \pm 8	0.87	0.12 ^t
		Non-dominant	40 \pm 4	40 \pm 7	0.77	0 ^t
	ER	Dominant	38 \pm 6	39 \pm 6	0.47	0.17 ^t
		Non-dominant	38 \pm 7	39 \pm 7	0.71	0.14 ^t
Posterior shoulder tightness (°)	Dominant		47 \pm 11	48 \pm 11	0.80	0.09 ^t
	Non-dominant		51 \pm 15	53 \pm 8	0.73	0.17 ^t

Abbreviations: n= number of participants, IR= Internal rotation, ER = External rotation, N.m = Newton meter, ^a= p-value between injured and uninjured, ^b=effect size between injured and uninjured

3.4.1.5 Discussion

This study was undertaken to explore the differences in ROM, IMS and posterior shoulder tightness between healthy versus injured fast bowlers. We found small but, statistically non-significant differences in the ROM, IMS and posterior shoulder tightness between the injured and uninjured shoulders. All the bowlers who subjectively reported shoulder pain in the injury history form also reported shoulder pain during the shoulder physiotherapy diagnostic

pain eliciting tests. The bowlers who did not experience any pain during the shoulder physiotherapy diagnostic pain eliciting tests also did not report any subjective shoulder pain. While the injured in this study were grouped based on the objective findings of the shoulder pain special tests, the accuracy of these special tests may itself be a limitation for the injury definition.

Fast bowlers were specifically sought as participants for the current study because, across several injury surveillance studies, fast bowler's shoulders have been highlighted as one of the most injury-prone (Dhillon et al., 2012, Laxmi et al., 2015, Ranson and Gregory, 2007, Sharma et al., 2012). In addition to the fielding-throwing workload, fast bowlers also need to frequently rotate their glenohumeral joint at high speeds to execute the bowling delivery. This frequent bowling and throwing involve frequent abduction and rotation. The repetitive abduction and rotation movement is performed by the rotator cuff muscles and can lead to their injury (Sundaram et al., 2012b).

It is well acknowledged that anatomical structural adaptations occur in a joint based on the demands of a sport (Borsa et al., 2008). Frequent bowling and throwing overload may potentially cause detrimental changes to the soft tissues stabilising the shoulder joint, similar to humeral retroversion and posterior capsule tightness observed with frequent pitching in baseball pitchers (Rosa et al., 2018). Among professional overhead throwing sports athletes, adaptations such as internal rotation deficit on the dominant shoulders have been reported (Harput et al., 2016, Almeida et al., 2013). Such adaptations may also develop among cricket fast bowlers due to bowling and throwing overload and may negatively affect shoulder rotation and thereby impact bowling performance.

Having a higher external rotation and decreased internal rotation range of motion has been commonly reported amongst overhead throwing sports athletes with shoulder injuries in comparison to uninjured athletes (Hurd et al., 2011, Johnson, 1992). Based on these reports, the current study was conducted to find out if ROM restrictions are present among fast bowlers with a shoulder injury. As shown in Table 3.16, the dominant shoulders ($76 \pm 8^\circ$) of the injured bowlers exhibited a slightly lower internal rotation in comparison to their non-dominant side ($78 \pm 12^\circ$). This observation was in contrast to uninjured bowlers, who exhibited slightly higher IR ROM on their dominant side. Although there was a non-

significant difference in the internal rotation ROM between the injured and uninjured shoulders, it must be noted that only a bilateral difference of 15-20° decrease in the internal rotation is referred to as glenohumeral internal rotation deficit (GIRD) (Keller et al., 2018). In the current study, the injured shoulders only displayed a mean 3° decrease in IR ROM compared to their uninjured counterparts. Internal rotation deficit may also be caused by tightness of the external rotators. The tightness of the external rotators can predispose them to strains during sudden explosive action. If the bowlers have not warmed up the shoulder rotators prior to a fast bowling spell, during sudden bowling action the external rotators could be strained. Also, if the bowlers are positioned in deep fielding positions and have to execute long fielding throws, the sudden explosive action could also strain the external rotators.

The injured bowlers exhibited a mean 4° decrease in ER ROM compared to their uninjured counterparts. Regardless of shoulder pain symptoms, all the bowlers displayed a mild increase in their ER ROM on their dominant side in comparison to their non-dominant side. We assume that this ER ROM gain may be due to joint adaptations caused by frequent cocking action while bowling and throwing. The 90° shoulder abduction and external rotation position, during the initiation of bowling and throwing is called the cocking action. The anterior aspect of the shoulder joint capsule is stretched every time during forceful abduction and external rotation. This adaptation has been proposed to cause ER ROM gain. The injured bowlers in the current study continued to bowl during the season despite their pain, so it is possible that the observed ROM differences might be due to adaptations occurring in the shoulder due to cricket. But to prove this, it is recommended to investigate ROM changes over an extended observation period to track if injured shoulders further decrease their internal rotation ROM. This may help identify if the ROM decrease is due to an injury. Identifying ROM deficits is vital for predicting joint injury risk. Therefore, it is recommended to conduct pre-season shoulder screening for all fast bowlers to identify players at increased shoulder injury risk, which will allow preventive steps to be implemented.

While it is known that changes to a joint's ROM are caused by either muscle tightness or ligament laxity (Mihata et al., 2015), we also measured the muscle strength of the shoulder-rotators. Cricket bowling requires repeated GH joint rotation regardless of the bowling delivery velocity and action (Sundaram et al., 2012b), this frequent rotation causes changes to

the rotator cuff muscles (Rosa et al., 2018). Associations of internal rotation deficits with rotator cuff tendinopathy and sub-acromial impingement (Morgan et al., 1998) have been established. As the force elicited by the shoulder's internal and external rotators positions the humeral head in the glenoid cavity (Alpert et al., 2000), it is crucial to maintain the internal and external rotator muscle strength symmetry (Flatow et al., 1994). The current study shows that there was no difference in the shoulder-rotators muscle strength between the injured and uninjured bowlers. However, the internal rotators were stronger than the external rotators for all of them. However, the slight difference of 4 N.m observed on the dominant shoulder's internal and external rotators, maybe an adaptation due to frequent throwing and bowling, which requires explosive internal rotation movement.

The external rotator muscles, infraspinatus and teres minor resist superior-anterior translation of the humerus during the internal rotation movement elicited by the subscapularis. Weaker external rotators and stronger internal rotators have been proposed to cause superior-anterior translation of humerus into the subacromial space compressing the supraspinatus tendon, which may manifest as chronic shoulder pain. Both the injured and uninjured bowlers exhibited a trend of slightly weaker external rotators compared to their internal rotators (dominant IR, 42 ± 8 N.m; dominant ER 39 ± 6 N.m; non-dominant IR, 40 ± 6 N.m; non-dominant ER 39 ± 7 N.m). The injured bowlers with stronger internal rotators would have to be examined using a radiological examination to find out if there is any reduction in the subacromial space. Prospective studies monitoring changes to the rotator cuff strength among fast bowlers during the playing and offseason are recommended. Developing exercise programmes specifically targeting the external rotators is also suggested. Implementation of such programmes will help fast bowlers handle bowling volume/intensity spikes, which is often seen in elite fast bowlers (Gabbett, 2016).

This is the first study which has recorded posterior shoulder tightness in cricketers. All the bowlers displayed slightly higher posterior shoulder tightness on their dominant side. As the shoulder joint capsule is fused with the joint's stabilisers, frequent throwing movements have been proposed to cause tightening of the posterior shoulder structures (Taniguchi et al., 2017). The ranges observed in this study are not indicative of any posterior shoulder capsule pathology. Previous studies confirming the presence of posterior capsule tightness reported ranges of only 30-40° on the affected arm and, most of these ranges were reported amongst

baseball pitchers with confirmed radiological reports (Wilk et al., 2015, Cowderoy et al., 2009).

The ER ROM observed amongst baseball pitchers from previous studies are higher than the ER ROM of the cricketers in this study (Marsh et al., 2018). This difference may also be due to the techniques used to measure shoulder ROM (Sabari et al., 1998). In the current study, measurements were done in supine decubitus with scapular movement stabilisation (Boon and Smith, 2000). Previous studies observing the differences in ROM based on active or passive ROM measurement techniques have been documented (Hayes et al., 2001). Measurement technique differences may partially explain differences in the posterior shoulder tightness values observed in the current study when compared to similar previous studies. Future prospective research measuring the posterior capsule tightness amongst fast bowlers with shoulder pain using medical radiology will provide a better understanding of the underlying GH joint pathology.

3.4.1.6 Conclusion

Regular screening of fast bowler's ROM, IMS and posterior shoulder tightness will detect anatomical changes which occur due to frequent bowling and throwing, and it will also help predict shoulder injury risk. Based on the screening results, targeted injury prevention could be implemented. The current study presents a profile of shoulder ROM, IMS and posterior shoulder tightness among fast bowlers. The results of this and future studies should be used as a reference for designing shoulder injury prevention exercise programmes for cricket fast bowlers.

3.5 Preface to study five

This section of the thesis relates to the fifth specific aim of the thesis:

To investigate the effects of an exercise programme on rotator cuff muscle strength and shoulder rotational range of motion.

The ACC study's main finding was that non-contact soft tissue injuries occurred due to strenuous repetitive movement and the 2015 CWC study revealed that fast bowling maybe the strenuous repetitive movement which predisposes a cricketer to injury. The third study results also suggest that the shoulders of the fast bowlers' experience repetitive movement related to overuse injuries. It could be suggested through the results of ACC study and the elite NZ fast bowlers' study this thesis quantified and established that the shoulder mostly experiences overuse injuries in the soft tissues of the glenohumeral joint.

Literature review of overuse shoulder injuries amongst cricketers and other overhead throwing sports athletes suggests that muscle strength asymmetry of rotator cuff and decrease in glenohumeral rotational range of motion may contribute to subacromial impingement and rotator cuff inflammation or vice versa. Study 4 observation also showed a slight trend towards a decreased range of motion and decreased muscle strength amongst fast bowlers with shoulder pain in comparison to healthy fast bowlers.

The rotator cuff muscle is responsible for maintaining glenohumeral joint stability and placing the humeral head position within the glenoid fossa during bowling and throwing movements (Manske and Ellenbecker, 2013). The commonly reported shoulder overuse conditions such as subacromial impingement and rotator cuff inflammation reported by the fast bowlers in study 3 means that, the rotator cuff strength may be reduced and the glenohumeral stability is compromised. Hence, strengthening the rotator cuff to maintain glenohumeral stability is suggested as a preventative approach to reduce shoulder overuse injuries. Also, the third stage of van Mechelen's sports injury prevention model suggests that preventive measures must be introduced to reduce injury risk (van Mechelen et al., 1992). With this in focus, study 5 was conducted as a randomised control trial to investigate the effects of a 6-week shoulder strengthening programme on fast bowlers' shoulder muscle strength and glenohumeral rotational range of motion.

3.5.1 Study five

Effect of a 6-week Indian clubbell strengthening programme on cricket fast bowlers' shoulder muscle strength and range of motion

Abstract

Background: Strengthening the shoulder rotator muscles contributes to glenohumeral stability. Therefore we wanted to test the effect of a 6-week Indian clubbell (ICB) exercise programme on shoulder range of motion (ROM) and isometric muscle strength (IMS).

Methods: Twenty-one male cricket fast bowlers were pair-matched on initial shoulder-rotator IMS and assigned to either an ICB shoulder strengthening group or a cricket training only group. Shoulder-rotator IMS and rotational ROM were measured at baseline, weeks 2, 4 and 6 using a handheld dynamometer and goniometer. The ICB programme (20 min/day, 3 days/week, 6 weeks) was designed to strengthen the shoulder-rotators. Two-tailed independent samples T-Tests of pre-to-post change scores compared between-group changes and two-tailed paired T-Tests compared within-group changes over the training period.

Results: Between groups (Clubbell: $n=11$, age 24 ± 6 y, mass 83 ± 8 kg, height 1.84 ± 0.05 m and Control: $n=10$, age 24 ± 5 y, mass 81 ± 8 kg, height 1.83 ± 0.11 m), bilateral internal rotators IMS increased more in the ICB group from baseline to week 6 ($P<0.05$). The ICB group's non-dominant arm's internal rotation (IR) ROM also had a greater increase (64 ± 10 to $70 \pm 6^\circ$, $P<0.05$) and the posterior shoulder tightness changed from 31 ± 4 to $37 \pm 3^\circ$ ($P<0.05$). Within the ICB group, IR IMS, IR ROM, external rotation ROM and posterior shoulder tightness all displayed beneficial changes ($P<0.05$).

Conclusion: Our findings suggest the ICB programme was beneficial, improving 4 of 5 strength and flexibility measures. Further refinement of the ICB exercises employed should target the shoulder external rotators more specifically.

3.5.1.2 Introduction

The fast bowling position has been identified as the most injury-prone cricket playing position (Orchard et al., 2006, Ranson and Gregory, 2007). Amongst fast bowlers, the lower back, thigh, shoulders and feet frequently experience pain either due to acute or overuse injuries (Frost and Chalmers, 2014). The shoulder pain experienced by cricket players has been attributed mostly due to an overuse origin (Orchard et al., 2009). The rotator cuff muscles are the most commonly affected soft tissue in the shoulder area due to repetitive stress. The rotator cuff muscles provide humeral compression, maintain glenohumeral joint stability and also create torque to rotate the glenohumeral joint (Cuéllar et al., 2017, Halder et al., 2000). For a fast bowler, rotator cuff strength is vital to compress the humeral head inside the glenoid cavity when the shoulder is rotated at high speeds during bowling (Alpert et al., 2000).

Cricket bowling requires frequent external and internal rotation and abduction of the glenohumeral joint. The external rotation is produced by the concentric contraction of the infraspinatus and teres minor while the internal rotation is produced by the concentric contraction of the subscapularis muscle (David et al., 2000b). The infraspinatus initiates shoulder abduction. During every fastball delivery, the abduction of the shoulder is initiated by the concentric contraction of the supraspinatus followed by the concentric contraction of the strong subscapularis muscle creating torque to elicit internal rotation (David et al., 2000b). This torque is matched by the eccentric contraction of the relatively weaker external rotators to stabilise the anterior humeral rotation and resist humeral translation (Noffal, 2003). This frequent rotation executed by fast bowlers during their career may weaken the external rotators in comparison to the internal rotators, and this phenomenon has also been observed amongst other overhead throwing sports athletes (Clarsen et al., 2014, Wang et al., 2000). A prolonged weakness of the external rotators may cause imbalance to the internal and external rotator strength (Clarsen et al., 2014). The muscle strength imbalance, over time also leads to a decrease in the internal rotation range of motion (Wang et al., 2000). The deficit of internal rotation range of motion has also been observed on the dominant shoulders of volleyball and handball players (Clarsen et al., 2014, Wang et al., 2000). Internal rotation range of motion deficit has been associated with tightening of the posterior shoulder structures and is also termed posterior shoulder tightness (Manske and Ellenbecker, 2013).

The infraspinatus and teres minor muscles resist superior-anterior translation of the humeral head. The weakness of the external rotators and the presence of strong internal rotators also may cause anterior translation of the humerus (Manske and Ellenbecker, 2013). This translation reduces the subacromial space. Reduction in subacromial space may cause friction between the acromion process and the supraspinatus tendon during shoulder abduction movement while bowling (Braman et al., 2014). The imbalance of internal-external rotator muscle strength is modifiable by strengthening the muscles to balance the force created by them (Timmons et al., 2012b). Beneficial changes in the rotator cuff strength due to exercise interventions have been observed amongst overhead throwing sports athletes (Niederbracht et al., 2008), but very few observations have been reported amongst cricket fast bowlers. Hence, the implementation of a rotator cuff strengthening programme and observing the changes in shoulder-rotators' isometric muscle strength and shoulder range of motion was the primary objective of this study.

Different exercise equipment can be used to strengthen the shoulder muscles, but for the current study, Indian clubbells were used. Indian clubbells are wooden clubbells shaped similar to bowling pins, with weights ranging from 1kg to 20kgs. Indian clubbells were popular shoulder strengthening and rehabilitation pieces of exercise equipment used by the British colonial troops in India during the 17th and 18th centuries, but the use of these clubbells as exercise equipment has declined in the modern gym environment (Sonnon, 2006). The advantage of using clubbells is the ability to exercise with them in multiple planes of movement. Clubbell swinging exercises also mimics a free-flowing pendula movement which may help improve shoulder range of motion. Pendulum exercises are commonly used in the conservative management of adhesive shoulder capsulitis and post-operative shoulder rehabilitation (Jain and Sharma, 2014). Hence, using the clubbells in a shoulder exercise programme should strengthen the rotator cuff and increase rotational range of motion. Therefore, the current study objective was to investigate the effect of a 6-week shoulder strengthening programme using Indian clubbells on shoulder rotational range of motion and isometric muscle strength.

3.5.1.3 Methods

Study design

Experimental randomised control trial

Participants

Participants in the study had to be at least 18 years of age, must have played club cricket with fast bowling as their primary playing position at least for five years and must have had no history of shoulder pain in the past 12 months. The University of Canterbury ethics committee approved the study (HEC Application 2017/52/LR-PS).

Experimental design

Participants were recruited into this randomised control trial through advertisements that asked for healthy male cricket fast bowlers who were willing to participate in a 6-week shoulder strengthening exercise programme. All volunteering participants were given information about the study purpose, and their consent was obtained. Based on the selection criteria, 21 male club cricket fast bowlers were recruited during the 2018-2019 playing season. The participants were pair-matched based on their initial dominant-arm shoulder-rotator (internal rotator + external rotator strength) isometric muscle strength and randomly assigned to either an Indian clubbell group or the cricket training only control group. Both group's participants were actively playing cricket throughout the study period. Both group participants were undergoing two days of cricket training and one match-day every week. Both group participants underwent the same type of cricket training, and the training frequency and duration were similar. The participants did not play any other sport during the study period. There was no blinding between the groups and the assessors.

The shoulder strengthening programme

For the duration of the exercise programme, participants in the Indian clubbell group performed the exercises 20 minutes per day for three non-consecutive days per week for a total of 6 weeks. Indian clubbells weighing, 500gms and 1 kg (Purpleheart armoury, USA) were used for the exercises. The exercise techniques were demonstrated to the Indian clubbell group participants to ensure adherence to the correct exercise technique. The Indian clubbell

group participants were also provided with demonstration videos and exercise worksheets. Each week the Indian clubbell group participants were given three exercise worksheets which explained the exercise's execution method, frequency, intensity and duration. After each session, the participants were required to record the date, time, exercise sets and repetitions in their worksheets. Both the Indian clubbell group and the control group participants continued their regular cricket training throughout the six week period.

Isometric muscle strength and range of motion testing

All tests were measured bilaterally with the participants in supine decubitus on an elevated plinth. Microfet 3 handheld dynamometer (HHD) (Hoggan Scientific, LLC, Salt Lake City, UT, USA) with intra-tester reliability (ICC 0.56-0.92) (Clarke et al., 2011) was used to measure the isometric muscle strength. The isometric muscle strength was evaluated with the shoulder in 30° shoulder abduction and 90° elbow flexion (Donatelli et al., 2000). External rotator isometric muscle strength was measured with the HHD positioned 2cm from the styloid process of the radius on the dorsal side of the forearm. The internal rotator isometric muscle strength was measured with the HHD positioned 2cm from the proximal wrist crease on the ventral side of the forearm. The participants were familiarised with isometric contractions and were instructed to perform internal or external rotation against the resisted HHD. The HHD was positioned in place by the tester, and the participants were asked to gradually build up force for 5 seconds against it. Triplicate measures were performed with the mean used for the data analysis.

A goniometer (EGM-422-EMI 12" Elite medical instruments, Fullerton, CA, USA) was used for measuring the range of motion and posterior shoulder tightness. Shoulder internal and external active range of motion was measured with the tested side in 90° glenohumeral abduction and 90° elbow flexion (Muir et al., 2010). Using the olecranon process as the axis point the goniometer's moving arm was moved with the forearm, while the goniometer's fixed arm was placed parallel to the ground. A towel was folded and placed as a wedge between the surface of the scapula and plinth for stability.

Posterior shoulder tightness was measured with the shoulder at 90° abduction and elbow at 90° flexion (Myers et al., 2006b). The acromioclavicular joint used as the goniometer axis, the fixed arm was parallel to the plinth, and the moving arm was in-line with the elbow joint's lateral epicondyle. Passive horizontal shoulder adduction was executed and, the

goniometer reading was recorded. A towel was folded and placed as a wedge between the surface of the scapula and plinth for stability. Resisted isometric muscle strength, rotational range of motion and posterior shoulder tightness was measured at week 0 (baseline), and at the end of weeks 2, 4 and 6 (post-test).

Reproducibility

The evaluator measured 11 subjects on two separate test sessions with seven days between sessions (N=11, age 24 ± 5 y, mass 81 ± 8 kg, height 1.83 ± 0.11 m) for intrarater reliability and the Intra-class correlation coefficient (ICC) scores for three trials were; ROM, ICC = 0.94 (df = 10, 95% CI: 0.84-0.98); IMS, ICC = 0.88 (df = 10, 95% CI: 0.71-0.96) and PST, ICC was 0.82 (N = 11, df = 10, 95% CI: 0.60-0.94).

Statistical Analysis

Two-tailed independent samples T-Tests of pre-to-post change scores compared between-group changes. While two-tailed paired T-Tests were used to compare within-group changes over the six weeks, all data were assessed at the $P < 0.05$ level of statistical significance. Furthermore, to demonstrate magnitudes of effects, Cohen's delta (d) was used to determine the differences of the effect size in ROM, IMS and PCT from baseline to the end of six weeks. The effect size was calculated within the control group participants and within the Indian clubbell group participants. Effect sizes were classified as trivial if $d \leq 0.2$, small if $d = 0.2 - 0.6$, moderate if $d = 0.6 - 1.2$, large if $d = 1.2 - 2.0$ and very large if $d = 2.0 - 4.0$.

3.5.1.4 Results

Table 3.17. Participant characteristics.

Group	Mass (kg)	Height (m)	Age (years)	Arm dominance Right/left	Cricket playing experience (years)
Control (n= 10)	81 ± 8	1.83 ± 0.11	24 ± 4	7/3	6 ± 4
Indian clubbell (n= 11)	83 ± 8	1.84 ± 0.05	24 ± 6	9/2	7 ± 6

Values are presented as means \pm range

The overall anthropometric measures were similar for both groups, as exhibited in Table 3.17, majority of the fast bowlers in both groups were right-handed dominant, and all participants have played cricket for a minimum of 6 years. Intragroup comparisons from baseline to week six changes revealed that, only the Indian clubbell group's non-dominant arm internal rotation range of motion increased ($P<0.05$) from 64 ± 10 to $70 \pm 6^\circ$, while the control group decreased from 68 ± 6 to $61 \pm 6^\circ$. The Indian clubbell group's bilateral internal rotator strength also increased ($P<0.05$) from 39 ± 7 to 45 ± 6 N.m on the dominant arm and 39 ± 5 to 45 ± 6 N.m on the non-dominant arm, while no increase was observed on the control group's arms. Posterior shoulder tightness also decreased ($P<0.05$) for the Indian clubbell group from 31 ± 4 to $37 \pm 3^\circ$ on the non-dominant arm, with no change observed in the control group as reported in Table 3.18.

Table 3.18. Changes to the range of motion, isometric muscle strength and posterior shoulder tightness throughout the six week period.

Group & variable	Arm	Baseline	Week 2	Week 4	Week 6	Cohen's <i>d</i>
Control's range of motion ($^\circ$)	ER dominant	74 ± 8	72 ± 6	73 ± 11	75 ± 4	0.83^m
	IR dominant	61 ± 2^a	62 ± 2	67 ± 8	68 ± 6^a	0.13^t
	ER non-dominant	71 ± 8	68 ± 5	71 ± 7	73 ± 5	0.74^m
	IR non-dominant	68 ± 6	60 ± 2	61 ± 10	61 ± 6^b	0.96^m
ICB's range of motion ($^\circ$)	ER dominant	74 ± 9^a	78 ± 9	79 ± 11	80 ± 6^a	0.83^m
	IR dominant	58 ± 6^a	65 ± 7	65 ± 7	67 ± 6^a	0.13^t
	ER non-dominant	71 ± 9^a	72 ± 9	74 ± 11	77 ± 5^a	0.74^m
	IR non-dominant	64 ± 10	64 ± 11	73 ± 6	70 ± 6^b	0.96^m
Control's isometric muscle strength (N.m)	ER dominant	39 ± 5	39 ± 6	38 ± 5	38 ± 4	0.73^m
	IR dominant	43 ± 7	43 ± 6	41 ± 8	42 ± 6^b	1.05^m
	ER non-dominant	38 ± 8	37 ± 6	37 ± 6	37 ± 5	0.73^m
	IR non-dominant	42 ± 7	41 ± 7	40 ± 8	40 ± 6^b	1.4^l
ICB's isometric muscle strength (N.m)	ER dominant	42 ± 5	38 ± 6	41 ± 7	42 ± 6	0.73^m
	IR dominant	39 ± 7^a	41 ± 5	44 ± 6	45 ± 6^{ab}	1.05^m
	ER non-dominant	41 ± 4	40 ± 6	42 ± 5	42 ± 5	0.73^m
	IR non-dominant	39 ± 5^a	40 ± 8	42 ± 6	45 ± 6^{ab}	1.4^l
Control's posterior shoulder tightness ($^\circ$)	Dominant	32 ± 5	34 ± 5	35 ± 4	35 ± 3	0.21^s
	Non-dominant	36 ± 3	37 ± 4	36 ± 4	36 ± 4^b	1.41^l
ICB's posterior shoulder tightness ($^\circ$)	Dominant	33 ± 4^a	36 ± 3	37 ± 5	37 ± 4^a	0.21^s
	Non-dominant	31 ± 4^a	35 ± 4	35 ± 5	37 ± 3^{ab}	1.41^l

Values are presented as mean \pm range, IR = Internal rotation, ER= External rotation, ICB = Indian clubbell group, N.m = Newton meter, ^a = $P < 0.05$ within-group comparison showing changes between baseline and week 6 ^b = $P < 0.05$ intragroup comparison between ICB and control group's week 6 changes.

3.5.1.5 Discussion

The current study objective was to investigate the effect of a 6-week shoulder strengthening programme using Indian clubbells on shoulder rotational range of motion and isometric muscle strength. An increase in shoulder-rotator strength aids in better glenohumeral joint stability (Wilk et al., 2015). In the current study the Indian clubbell group's internal rotators strength increased bilaterally from 39 N.m at baseline to 45 N.m at the end of week 6, this demonstrates the effectiveness of the Indian clubbell exercise programme for the improvement in internal rotator strength.

The indifference (42 N.m at baseline to 42 N.m at week 6) observed in the strength of the external rotators as displayed in Table 3.18, implies that the exercises require modification to target the external rotators. As the external rotators are smaller and weaker in comparison to the stronger and larger internal rotators (Cowderoy et al., 2009), it is critical to target and strengthen the external rotators to maintain the internal-external rotator strength ratio and help maintain the positioning of the humerus in the glenoid cavity (Mulligan et al., 2004). No significant loss of muscle strength was observed even in the control group, and this may be because both group participants regularly played cricket three times per week throughout the study period. As throwing and bowling involve frequent internal rotation, during the playing season, the increase in bowling and throwing volume might continue to strengthen the internal rotators and may lead to an imbalance in the internal-external rotator muscle strength ratio (Bell-Jenje and Gray, 2005). An imbalance of rotator cuff muscle strength is associated with impingement syndrome and glenohumeral instability (Watts et al., 2017). It is therefore essential to monitor and strengthen the external rotators.

There was no significant change observed in the external rotators in comparison to the external rotators. Stronger internal rotators will lead to humeral anterior translation and subacromial impingement (Marsh et al., 2018), therefore it is recommended to modify the exercise programme and include more external rotator exercises in the set of prescribed

exercises. The presence of stronger internal rotators compared to external rotators and its effect on bowling and throwing performance has to be researched. Existing scientific literature (Shim and Niederbracht, 2014) suggests that shoulder exercise programmes could only include external rotator exercises (Niederbracht et al., 2008) as the internal rotators are stronger naturally and they get strengthened due to the demands placed on the internal rotators due to involvement in throwing sports (Shire et al., 2017). The study period coincided with the start of the playing season. Therefore, the range of motion increase might also be due to both group participants undergoing cricket-training three times per week. Nevertheless, the between-groups comparison revealed that the Indian clubbells group participants displayed a greater range of motion increase, with a 16% increase in the dominant arm's internal rotation range of motion and 8% increase in the dominant arm's external rotation range of motion as shown in Table 3.18. More specifically the Indian clubbell group's non-dominant arm's internal rotation range of motion increased ($P<0.05$) from $64 \pm 10^\circ$ at baseline to $70 \pm 6^\circ$ at week 6, while the control group displayed a 10% decrease to their non-dominant arm internal rotation range of motion. This suggests that the Indian clubbell exercises might improve shoulder rotational range of motion and cricket bowlers could also use it during pre-match shoulder warmups. Detecting deficits in range of motion is critical for injury risk prediction, and evidence proposes that the range of motion deficits can be rectified.

Glenohumeral internal rotation deficit is associated with posterior shoulder tightness, and it has been commonly reported amongst overhead athletes. Likewise, only the Indian clubbell group's non-dominant side internal rotation range of motion increased by 6° ($P<0.05$), while their posterior shoulder tightness decreased by 6° ($P<0.05$). Although changes to posterior shoulder tightness was monitored during the study period, as the participants were healthy cricketers, the observed internal rotation range of motion deficit and posterior shoulder tightness values are not critical, if the same measurements were observed on injured players, the mean values might be lower (Myers et al., 2007). Although rotator cuff muscle strength asymmetry, internal rotation deficit and posterior shoulder tightness are associated with subacromial impingement, subacromial bursitis and scapular dyskinesia (McClure et al., 2009), it is unclear if the direct cause of injury is a structural anatomic adaptation due to cricket. However, the maintenance of the rotational range of motion and balanced rotator cuff muscle strength is recommended for a healthy shoulder. Based on the current study results

indicate we propose that the Indian clubbell programme maintains shoulder rotational range of motion and it strengthens the rotator cuff. Hence, these Indian clubbell exercises could be used to develop future effective shoulder injury prevention programme.

3.5.1.6 Conclusion

Shoulder stability and flexibility is vital for cricket fast bowlers to execute consistent high-speed deliveries with accuracy. Maintenance of shoulder-rotator muscle strength and range of motion is also a requisite for shoulder injury prevention. While there have been many methods to strengthen the shoulder and avoid injuries, this study is the first to investigate a shoulder strengthening programme with a cohort of cricket fast bowlers using Indian clubbells. The results of the study suggest that programmed exercises targeting the rotator cuff muscles utilising Indian clubbells will increase shoulder-rotators isometric muscle strength, rotational range of motion and decrease posterior shoulder tightness.

CHAPTER FOUR

Discussion

4.1 Overview of the thesis

All the studies in this thesis were conducted according to van Mechelen's sports injury prevention model. Based on the stages suggested in the model, cricket-related injuries were quantified, the injury aetiology was explored, and an exercise programme was introduced. Study 1 quantified nationwide cricket-related injury prevalence among the general population. One of the main findings of study 1 was, it revealed that repetitive and strenuous movement mostly caused non-contact soft tissue injuries to the shoulder. Study 2 quantified injury prevalence among an elite cricket population and identified that bowling is an injury-prone activity and the fast bowling position is highly injury-prone. Study 3 also quantified injury prevalence specifically among New Zealand's elite fast bowlers and found that the shoulder is one of the most injury-prone body parts and common injury diagnoses of the shoulder were related to the rotator cuff and subacromial space.

The results of the first three studies were interpreted using past cricket injury research, and an assessment was conducted in study 4 to find out the difference in shoulder range of motion and muscle strength between injured and uninjured fast bowlers. Based on the investigations and literature review, study 5 was conducted to improve the range of motion and muscle strength of fast bowler's shoulders. Study 5 results showed that the introduced exercise programme increased range of motion, internal rotator muscle strength and reduced posterior shoulder tightness. Therefore, it is suggested that the introduced exercise programme could be used as part of a shoulder injury prevention programme as it might strengthen the glenohumeral joint's dynamic stabilisers and thereby maintain joint stability and this may reduce future shoulder injury occurrence. The following sections will provide an elaborate discussion on the findings of the five studies, compare it with previous scientific literature and suggest strategies for shoulder injury prevention.

4.1.1 Popularity of cricket and the nationwide cricket injury prevalence

Cricket has emerged as an increasingly popular sport since the inception of T20 cricket format in 2006. The success of T20 cricket has been welcomed by most member nations of the ICC, and this could be observed by the increase in the number of international cricket tournaments held across the globe. This popularity of cricket in the last decade may also have influenced the number of people wanting to participate in the sport. The success of the respective national teams in international tournaments also plays a vital role in garnering

public interest towards the sport, and this may also lead to a large number of the general public playing the sport. The success of a national team in international tournaments might bring corporate sponsorship and may help the national cricket boards to roll out youth programmes to recruit future talents to represent the national teams. All these factors may lead to an increase in nationwide public participation. In order to play at an elite level, aspiring youth start training for cricket at an early age. As the number of people wanting to play cricket increases, it is essential to monitor and control the cricket-related injury prevalence. In order to control cricket-related injury prevalence, targeted injury prevention programmes should be implemented as a public health measure. Injury prevention programmes should also be implemented with an evidence-based approach.

An evidence-based approach to control cricket-related injury prevalence relies on quality injury surveillance. Analysing the results of cricket injury surveillance will help identify injury-prone body parts and execute prevention strategies. The majority of injury surveillance reports published have been conducted on elite or sub-elite cricket cohorts. While the observations from those studies will help understand cricket injury prevalence, the injury mechanisms and causes of cricket injuries may differ between an elite cricketering population and the general population. The cricket match and training workload of an elite cricketer is higher than a recreational cricketer. Elite cricketers often train and play cricket up to five days in a week, whereas recreational cricketers often play only one day during the weekends.

If nationwide cricket injury prevention programmes have to be implemented there is a need to understand the injury type and its cause. Causes of injuries among elite cricketers may differ in comparison to recreational cricketers. Due to frequent cricket training, elite cricketers may have a higher prevalence of overuse injuries, whereas recreational cricketers might not be conditioned well and may be subjected to more acute strain injuries. Also, recreational cricketers, in some cases, may not use appropriate protective gear or techniques and may encounter more injuries due to impact or fall. Considering all these factors, study 1 of this thesis was conducted to include all people who were injured while playing cricket in New Zealand. This data includes everyone from recreational cricketers, school-grade cricketers to the elite first-class cricketer as all would have been living in New Zealand during the 12 years of study.

During the 12 years, the nationwide age-standardised injury incidence for male cricketers increased by 45% with 2771 injuries per 10000 people in the year 2005 to 3935 injuries per 10000 people in the year 2016. While this substantial increase in injury incidence is of concern, the reason behind this increase in injury incidence is not apparent. Currently, as there is no existing injury surveillance study which has reported on a nationwide cricket-related injury incidence amongst the general public, no comparative suggestion could be provided. The injury incidence rates for the ACC study have been calculated based on the population increase in New Zealand over the 12 years. Hence, the only plausible explanation for the increase in injury incidence over the 12 years might be due to more people participating in cricket nationwide.

Since the inception of the T20 cricket format, it has become easier to access internationally played cricket matches through internet streaming media. Also, as many national-level elite cricketers have increased chances to sign playing contracts with international private cricket teams, the visibility of cricket as a career choice has improved. These reasons may also have caused a surge in the popularity of the sport and might have led to larger participation numbers. However, further investigation is required to analyse if the increase in injury incidence is directly due to the increase in nationwide cricket participation.

4.1.2 Injury-prone body areas due to cricket participation

In the ACC study, the most injured body areas due to nationwide cricket participation were the wrist/hand (19.7%), back/spine (15.7%) and shoulder (11.2%). The wrist/hand area was consistently the most injured body area over the 12 years. The majority of those wrist/hand injuries were contact injuries and involved fractures and dislocations. The specific cricket activity that caused these wrist/hand injuries were not recorded by ACC data so the exact cause of those injuries could not be ascertained. However, a study amongst Australian elite male cricketers revealed that 11% of all sustained injuries occurred on the wrist/hand, and they occurred mostly during fielding (Orchard et al., 2002). While it is not known what specific cricket activity caused so many contact injuries to the wrist/hand in the general population, it is suggested that either batting without gloves or not using the correct ball-catching techniques while fielding may have caused those wrist/hand fractures and dislocations. In the 2015 CWC injury surveillance study, only three hand injuries were recorded, and hand injuries were the fourth most common injury. The fast bowler, batsmen

and wicketkeeper, each sustained one hand injury and they were reported to occur during fielding.

Similarly, in the NZ elite fast bowler study, there were four acute wrist/hand injuries reported by the fast bowlers, and they also occurred while fielding. This indicates that the leading cause for wrist/hand injuries may be either contact with the fast-moving ball or landing on the hands during fielding. With such common occurrence of wrist/hand injuries even amongst elite cricketers, preventive steps must be implemented nationwide to reduce the incidence of wrist/hand injuries amongst general population playing cricket. In order to prevent wrist/hand injury prevalence, education is necessary to promote correct fielding techniques. Using protective sports equipment to prevent such contact injuries is also recommended.

The back/spine has consistently been the second most injury-prone body area among the general public due to cricket participation. This finding is quite similar to the lumbar injury prevalence commonly reported amongst elite cricketers (Hulin et al., 2014a). Alarming the back/spine injury prevalence increased by 76% with 718 injuries in 2006 to 1262 injuries in 2016. The primary injury aetiology for lower back cricket injuries is cited as overuse (Arora et al., 2014). Repetitive stress with reduced recovery periods has been suggested as the main contributing factor for lower back injuries (Bayne et al., 2016). In the ACC study, almost all of the back/spine injuries were recorded as soft tissue injuries (12097 injuries) with only 26 injuries due to fracture/dislocation. Contact injuries to the back/spine were only 37% while non-contact injuries were 61%. The soft tissues of the spine such as the intervertebral discs, erector spinae muscles and the longitudinal ligaments potentially are the anatomical structures most affected due to cricket participation.

Amongst elite cricketers, the most commonly reported lower back injury diagnoses are intervertebral disc prolapse, lumbar spondylitis and lumbar stress fractures (Johnson et al., 2012). Most of these back injury diagnoses among elite cricketers have been suggested to occur due to repetitive workload stress placed on the soft tissues over a prolonged period (Greig and Nagy, 2017). While acute disc prolapse could occur due to sudden loading, like performing the deadlift with a rounded back, the chances for such an anatomical position to be adopted while playing cricket is highly unlikely. Also, cricket does not involve lifting heavy objects or contact with another player. Therefore, it is suggested that either repetitive

and strenuous bowling or batting for long periods using a heavy bat may have contributed to the back/spine injury prevalence amongst the general public. These back/spine injuries might be more due to overuse.

Lumbar stress fractures have a higher prevalence amongst elite cricketers. In the NZ elite fast bowler study, lower back stress fractures (5/47) were the highest occurring injury. But in the ACC study, only 26 spinal fractures out of 12097 back/spine were recorded. Therefore, it is suggested that the injury mechanism between elite cricketers and general public playing cricket is different. As the ACC data has not recorded the cricket-specific activity at the time of an injury, it is difficult to conclude on the cricket activity, which caused the majority of back/spine injuries. Injury surveillance studies amongst elite cricketers suggest that the cricket batting and fast bowling actions both could affect the soft tissue structures of the lower back (Morton et al., 2014). Prolonged bending of the spine and swinging a heavy cricket bat, may affect the spinal structures. Repetitive side-flexion combined with the ground reaction forces during fast bowling may also contribute to lumbar injuries.

In the ACC study, the leading causes of non-contact injuries were repetitive movement and strenuous movement without lifting. Hence, it is suggested that the cricket-related back/spine injuries amongst general public may be due to repetitive overuse which mainly affects the soft tissues, but the cricket workload is not as high as elite cricketers to cause lumbar stress fractures. Therefore, to prevent and reduce back/spine cricket injuries among the general public, it is recommended to condition the spine with strengthening exercises (Bayne et al., 2016) and also to incorporate proper warmup techniques before cricket participation (Bayne et al., 2011).

A healthy shoulder is vital for a cricketer to execute fielding-throwing and bowling. Previous research (Aginsky et al., 2004) suggests that amongst overhead throwing athletes, the leading cause of shoulder pain is overuse which affects the shoulder joint's soft tissues. In the ACC study, 10% of all injuries were soft tissue injuries to the shoulder. The shoulder injuries increased by 85% from 468 injuries in 2006 to 864 injuries in 2016. Even though the reason behind the increase in injury prevalence is not fully understood, the cause of these shoulder injuries must be explored. Over the 12 years, out of 8636 shoulder injuries, 55% were non-contact injuries. The ACC data describes the cause for non-contact injuries as due to

repetitive and strenuous movement. Therefore, the 55% non-contact shoulder injuries may have occurred due to repetitive and strenuous bowling, throwing or batting.

In comparison, the New Zealand elite fast bowler injury surveillance study reveals that out of the four acute shoulder injuries, two occurred during fast bowling and two during fielding-throwing. While these shoulder injuries were due to acute onset, the shoulder pain was not severe enough as the six bowlers together missed only five days due to shoulder pain. This suggests that non-contact soft tissue injuries to the shoulder area due to repetitive strenuous movement but the severity of shoulder pain intolerable by cricketers that they can continue to play. Even if a shoulder injury is not severe enough to miss a match, shoulder pain may affect bowling performance and limit participation in strength training sessions for an elite cricketer.

Current injury surveillance studies have reported the shoulder as the fourth most commonly injured body part (Dhillon et al., 2012). But shoulder prevalence rates differ depending on the duration of the study. Higher (23%) injury prevalence rates (Ranson and Gregory, 2007) are reported during long-term injury surveillance studies in comparison to lower (7%) injury prevalence reported in short-term tournament injury surveillance reports (Ranson et al., 2013). The suggested reason behind this discrepancy in shoulder injury prevalence is said to be the nature and severity of shoulder injuries.

Cricket-related shoulder pain is mostly due to overuse (Bell-Jenje and Gray, 2005). The presentation of shoulder pain severe enough to impact bowling might take weeks or even months to develop (Ranson and Gregory, 2007). Moreover, this shoulder pain will not be picked up in short-term tournament injury surveillances. Cricketers may be reluctant to seek medical attention at an early stage of pain and will often continue to play during this period with some degree of tolerable pain (Ranson and Gregory, 2007). Pain elicited in the shoulder may be an indication of some level of pathological change occurring to the shoulder joint's soft tissues. Continuing to undergo cricket-training ignoring the pain, may cause structural adaptations to the rotator cuff muscle, subacromial bursa and glenoid labrum.

The New Zealand elite fast bowler's study revealed that the injured bowlers reported specific shoulder conditions such as rotator cuff inflammation and subacromial impingement.

Shoulder conditions such as subacromial impingement or rotator cuff inflammation are associated with anatomical changes like muscle asymmetry of the shoulder rotators and deficits of a rotational range of motion (Mackenzie et al., 2015). The pathological changes may decrease the rotational range of motion and decrease the rotator cuff muscle strength or vice versa. Hence, when cricketers report shoulder pain, even if it is not severe enough to miss matches, assessment of their shoulder range of motion, muscle strength and scapular dyskinesis must be undertaken to detect the anatomical adaptations and initiate preventative measure.

4.1.3 The importance of cricket injury surveillance

Injury surveillance is vital for quantifying and analysing injury predisposition. Without injury surveillance, evidence-based injury prevention cannot be implemented (Newman et al., 2005). The majority of sports medicine literature is an outcome of documentation and analysis of sports injury occurrences. Identifying injury-prone playing positions, injury-prone body areas, injury mechanism, injury type and injury risk factors are all critical for the execution of targeted injury prevention strategies.

Cricket has evolved into a global sport with large spectator numbers (Khondker and Robertson, 2018). Winning the ICC 50-over Cricket World Cup is considered the pinnacle of sports achievement in cricket and every aspiring cricketer would want to be a part of it. Thus, for such a popular world-class tournament, every participating team's focus should be ensuring that all matches are played without any of their players getting injured. As injury affects playing performance and if performance is affected, it affects the team's winning chances. Hence, teams implement appropriate injury prevention strategies to reduce any chance of injury occurrence. Yet, most cricket injury surveillance reports have been conducted on individual national teams with the exception of the 2011 CWC study (Ranson et al., 2013).

There was no official injury surveillance conducted during the 2015 CWC. Therefore, the only method to collect injury prevalence was to collect the injuries reported to the media and collate it with the number of matches missed by players due to the injury. Amidst the study design, the 2015 CWC study highlighted that fast bowlers missed the highest number of matches due to injuries, and this is a consistent finding with the 2011 CWC study (Ranson et

al., 2013). The results also revealed that fast bowlers missed 31 matches due to injuries and nine injuries occurred due to bowling. While the study design was based on media reports, all injuries reported were prospectively observed, and the media releases were obtained from several sources. As players missed the consecutive matches, following an injury report, it also added credibility to the injuries reported to the media. The results could only be compared with the 2011 CWC study. The 2011 CWC study, was conducted with cooperation from team medical staff and coaches, whereas, the current study was solely based on media reports. Due to this reason, non-time loss injuries could not be recorded in the 2015 CWC study, and this is a limitation to the study design. This method of injury surveillance also has limitations due to the lack of data validation from reliable sources. Therefore, early adoption of a proper injury surveillance design with approval from ICC and team medical staff will help collect quality injury reports during future CWC events.

The injury surveillance design is fundamental to ensure the quality of the injury surveillance results. Cricket injury surveillance can be conducted retrospectively or prospectively. Retrospective injury surveillance requires less time and resources. The data which has been already collected could be analysed. Although, the quality of the variables used to collect the cricket injury reports must be ensured because future modifications cannot be made to data that has already been collected. This limitation was observed in the ACC study, which analysed the nationwide cricket-related injury incidence amongst the general public. The lack of information on the specific cricket activity which caused injury onset was not used as a variable to collect the data. Without this information, the 77212 injuries could not be classified into bowling, batting or fielding injuries.

Another variable which could have been used is specific injury diagnoses. If this information was available targeted injury prevention based on the diagnoses could be implemented. For example, among the 7396 back/spine non-contact injuries, information on whether they were lumbar disc prolapse or lumbar spondylitis or any other lumbar conditions could not be obtained. Also, among the 4768 non-contact shoulder injuries, information on whether they were subacromial bursitis, supraspinatus tendinopathy or labral lesions or any other shoulder conditions could not be obtained. In comparison, the NZ elite fast bowler's injury surveillance provided information on the medical diagnoses such as lumbar stress fractures and rotator cuff strain. Thus, ensuring the usage of correct variables while

conducting cricket injury surveillance data will help obtain explicit descriptive data. Moreover, this data could be used to prescribe evidence-based injury prevention methods.

The data collected from the elite New Zealand fast bowlers was a self-reported survey of injury occurrences which they experienced in the last 12 months. The study was designed as a retrospective design because prospective injury surveillance requires a long term longitudinal observation period. The current study period was not adequate to conduct longitudinal prospective injury surveillance. Also, the university ethics committee does not allow retrospective ethics application on identifiable recorded medical data. These elite cricketers might not have initially consented to get treated by a medical practitioner for research purposes. The elite fast bowlers recruited into the study were living across the country, playing for six different regional cricket associations. Therefore, they would have consulted their family practitioners closer to their regional cricket association when an injury occurs. Therefore, the variables used to record the injuries might be different for each player. These discrepancies would affect the quality of the data collected, and it would be difficult to compare the injury prevalence, causes and diagnoses.

The retrospective data collection method was also implemented to collect data directly from the players with a new injury definition. In the survey, players could record a musculoskeletal injury of any severity and not just injuries which caused them to miss matches. Hence, due to the aforementioned reasons, the New Zealand elite fast bowlers' injury surveillance study was designed retrospectively, so that all the fast bowlers would get the same set of questions and to ensure even analysis of the results.

The limitation of retrospective injury surveillance is that it may not accurately report injury prevalence because it relies on the participant's response and lacks the medical practitioner's verification. However, as the participants in the current study were professional cricketers who keep training diaries, we believe the data collected may contain a higher degree of accuracy and reliability. Retrospective injury surveillance methods could have recall bias, where some injury information could have been lost due to failure to recall the injury event, and also the tendency to over-report the severity of the past injuries concerning the days missed due to an injury (Harel et al., 1994). Hence, information related to days missed due to an injury was not taken into account and analysed. Previous research suggests monitoring of workload and correlating it with injury incidences (Dennis et al., 2005). But as this study was

retrospective, the training and match workload could not be obtained directly from the cricketers. Prospective cricket match and training workload monitoring and correlation with injury incidences will also take longer study duration and did not suit the time frame of this thesis, due to this reason, a prospective design could not be undertaken.

4.1.4 The fast bowler and shoulder injuries

The fast bowling position has been consistently identified as the most injury-prone for over 20 years. Although cricket shoulder injury prevalence has been reported by previous researchers, very few studies have reported fast bowling related shoulder injuries. Amongst elite Australian cricketers, 6% of shoulder tendon injuries were reported to occur due to bowling, but the aetiology was not described (Orchard et al., 2002). In the ACC study, 55% of shoulder injuries were recorded as non-contact injuries which may have been caused due to repetitive and strenuous movement. In the shoulder, the soft tissues which may be injured due to repetitive and strenuous movement are the rotator cuff muscle, deltoids muscle, biceps tendon, acromioclavicular ligament, glenohumeral ligament, subacromial bursa, shoulder joint capsule and glenoid labrum. The most commonly reported shoulder tendon injuries occur on either the rotator cuff or biceps (Orchard et al., 2002). The cricket bowling and throwing actions, mainly involve forceful glenohumeral rotation with very little forceful elbow flexion.

With regards to the biceps tendon, mostly only forceful eccentric contraction during elbow extension would strain the biceps tendon (Olivier et al., 2016b, Orchard et al., 2015). During the bowling action, very little force is required to flex and extend the elbow, so the chances of straining the biceps due to cricket bowling are less likely. Radiological imaging studies of overhead throwing athletes with shoulder pain have identified that the rotator cuff undergoes pathological changes due to the repetitive use (Taniguchi et al., 2017, Murakami et al., 2018). In the elite New Zealand fast bowler study, shoulder injuries were related to the rotator cuff. The rotator cuff is muscle mainly responsible for glenohumeral rotation and stability, and it is the muscle which may be most subjective to stress due to frequent bowling and throwing (Bell-Jenje and Gray, 2005). So it could be concluded that the most injury-prone shoulder muscle would be the rotator cuff muscles.

Throwing in cricket has been commonly cited as a cause for cricketing shoulder injuries (Whiteley and Ocegüera, 2016, Sgroi and Zajac, 2018, Mihata et al., 2015). The throwing action involves shoulder external rotation and abduction with elbow flexion and continues to shoulder internal rotation, adduction and elbow extension. If this movement is analysed, the abduction, external and internal rotation movements are all elicited due to force produced by the rotator cuff muscle (David et al., 2000a). The contrast between cricket bowling action and the throwing action is that bowling involves a minimum of six balls bowled consequently, whereas a fielding throw in comparison will occur infrequently, but can occur somewhat frequently in training (Dennis et al., 2005). The sudden explosive nature of a fielding throw may contribute to a rotator cuff strain. Similarly, depending on the number of balls bowled, bowling also will contribute to rotator cuff strain, as it also requires repetitive abduction and rotation. This means the risk for shoulder injury is higher for a cricketer who bowls a higher number of balls in comparison to other players (Dennis et al., 2005) especially as because all players need to throw during fielding, but the bowler has to also bowl consecutive balls as well as throw during fielding.

Potentially, another reason for increased rotator cuff injury risk for a fast bowler is with regards to fielding positions. Fast bowlers are often placed in fielding positions such as deep backward square, fine leg and third man because from these positions the fast bowler will be at the correct end for their bowling over. This positioning means, the fast bowler has to execute long distance forceful overarm throwing to the wicket and this will require sudden explosive rotational movement and this sudden rotational throwing movement requires higher force elicited by the rotator cuff. Therefore, it is suggested that predisposition for the rotator cuff to be injured in the shoulder is higher for a fast bowler in comparison to other positions. This suggestion is also supported by previous studies, as it was found that the force elicited by the rotator cuff to bowl a fastball was much higher than the force elicited to bowl a spin ball (Gregory et al., 2002, Sundaram et al., 2012a, Ali et al., 2016). So considering factors such as higher force produced to complete a fast bowling action, bowling high numbers of overs in a match and long-distance fielding-throwing it is suggested that the fast bowler is more likely to experience rotator cuff injury in comparison to batsmen, wicket keepers and spin bowlers.

4.1.5 Fast bowling and subacromial space pathology

In the elite New Zealand fast bowler study, shoulder pathologies such as rotator cuff pathology and subacromial impingement were reported as the medical diagnoses. Although very few cricket-related subacromial conditions have previously been reported (Bell-Jenje and Gray, 2005) research suggests that the majority of non-contact shoulder injuries have been associated with pathologies of the subacromial space (van der Windt et al., 1995). Numerous studies have established the association between rotator cuff tendinopathy, subacromial bursitis and subacromial impingement (Mackenzie et al., 2015). Subacromial space pathology may involve and include the rotator cuff tendons and subacromial bursa. These soft tissues lie in the 1.5cm space beneath the acromion process of the scapula (Bigliani and Levine, 1997). The fast bowling shoulder action starts with glenohumeral abduction. During shoulder abduction, the subacromial space reduces and contact between the acromion's inferior process and the subacromial tissues increases (Mihata et al., 2015, Watts et al., 2017). This suggests that repetitive bowling action would involve repetitive mechanical compression of the subacromial tissues. Frequent compression of the subacromial tissues may also present as chronic impingement related shoulder pain.

Impingement is categorised into three stages (Neer, 1983). The first stage involves oedema and haemorrhage of the rotator cuff tendons and/or the bursa. The second stage involves inflammation, rotator cuff tendonitis and fibrosis. The third stage involves grade 3 rotator cuff strains. Most subacromial shoulder conditions are overuse related injuries involving the rotator cuff muscles (Brukner and Khan K., 2012). Rotator cuff injury may be due to extrinsic or intrinsic causes (Michener et al., 2003). Frequent bowling involves repetitive glenohumeral abduction and rotation. Glenohumeral abduction and rotation are elicited by rotator cuff muscles. This repetitive stress may cause partial or full tears to rotator cuff tendons, and this is identified as an intrinsic cause (Arora et al., 2015). Repetitive abduction during bowling also causes mechanical compression of the rotator cuff tendon by the acromion process, and this is identified as an extrinsic cause (Page, 2011).

Impingement also occurs posteriorly when the arm is abducted and externally rotated during the cocking phase of throwing (Scher et al., 2010). In this throwing position, the rotator cuff tendon is compressed between the superior posterior glenoid rim and the humeral head. This may be the main injury mechanism, likely to cause shoulder pain during throwing (Bell-

Jenje, 2018). This type of impingement may occur during sudden explosive throwing actions. Therefore, it is suggested that frequent repetitive shoulder abduction causes rotator cuff inflammation. The rotator cuff inflammation may cause further compression and present as chronic impingement pain. Thus it could be concluded that fast bowlers who complain of a gradual increase in shoulder pain, may most likely sustain rotator cuff pathology and impingement related conditions.

4.1.6 Rotator cuff muscle strength and shoulder injury

Quantification of the nationwide cricket-related injury prevalence revealed that there is a high prevalence of non-contact soft tissue injuries to the shoulder. Furthermore, the literature review suggests that among athletes, the most common non-contact soft tissue shoulder injuries are subacromial impingement and rotator cuff pathology (Page, 2011, Weiss et al., 2018). Frequent repetitive abduction may be the primary injury mechanism of subacromial impingement and rotator cuff pathology (Mihata et al., 2015). The 2015 CWC study revealed that bowling is an injury-prone activity and fast bowlers are the most injury-prone. Research confirms that the fast bowling movement may involve strenuous and repetitive movement, in comparison to other cricketing positions (Gregory et al., 2002, Sundaram et al., 2012a, Ali et al., 2016). Strenuous and repetitive movement may cause inflammation to the rotator cuff tendon, and rotator cuff inflammation may cause subacromial impingement (Laxmi et al., 2015, Watts et al., 2017, Weiss et al., 2018). This recommendation is supportive of the New Zealand elite fast bowler study findings, where players reported that bowling and fielding caused rotator cuff inflammation and subacromial impingement. Apart from this finding various factors such as rotator cuff muscle strength asymmetry, range of motion deficit, scapular dyskinesis, pectoralis minor shortening, posterior shoulder tightness have all been commonly cited to either contribute to subacromial impingement or vice versa (Pardiwala et al., 2018).

The stability of the glenohumeral joint relies on the dynamic stabilisers and static stabilisers. If these stabilisers are affected, it further affects the joint dynamics, and that might affect the range of motion and eventually the bowling and throwing action. The rotator cuff muscles act as the glenohumeral joint's dynamic stabilisers. Hence, any initial adaptations due to repetitive bowling workload may first affect the rotator cuff muscles (Teyhen et al., 2008).

Stronger internal rotators and weaker external rotators may occur as an adaptation due to the throwing demands of the playing position. The initial adaptation due to rotator cuff strength asymmetry may further affect the rotational range of motion. A deficit in internal rotation and an increase in external rotation on the dominant throwing arm has also been reported (Sundaram et al., 2012b). These deficits in range of motion may be due to the presence of prolonged rotator cuff strength asymmetry. Long term deficits of internal rotation may also cause tightness of the posterior shoulder joint capsule. The presence of posterior capsule tightness is also exhibited by baseball pitchers with internal rotation deficit (Clabbers et al., 2007, Myers et al., 2006a, Hurd et al., 2011).

Furthermore, the long term internal rotator tightness may also cause superior-anterior translation of the humeral head during shoulder abduction movements (Kirchhoff and Imhoff, 2010). Fast bowlers are required to repeatedly abduct and perform shoulder circumduction to execute the ball delivery. Glenohumeral abduction reduces the subacromial space (Mihata et al., 2015, Watts et al., 2017). In addition to bowling abduction, superior-anterior translation of the humeral head will also encroach the subacromial space and reduce it. Reduction in subacromial space will mechanically compress the subacromial soft tissues such as the rotator cuff tendons and subacromial bursa. Along with these anatomical structural changes, the presence of stronger internal rotators may rotate the humerus anteriorly. The anterior rotation may cause tightness and shortening of the pectoralis minor muscle. In support of this explanation, a study among baseball players reported that tightness of pectoralis minor is associated with subacromial impingement pain (Hodgins et al., 2017). The tightness of the pectoral muscles may also affect scapulothoracic movement, as the scapular stabilising muscles are stretched continuously and may become weaker (Lewis and Valentine, 2007). The weakness of the scapular stabilising muscle leads to anterior tipping of the acromion process, which further reduces the subacromial space (Lopes et al., 2015).

Any of these above-mentioned conditions may elicit pain in the shoulder. Depending on the severity of the pain, the player may continue to play or choose to miss matches (Ranson and Gregory, 2007). Any early signs of a range of motion restrictions are only an indicator of the underlying pathology. As most subacromial space pathology is interrelated, it is essential to assess and monitor any reporting of gradual shoulder pain onset (Mackenzie et al., 2015).

Hence, based on all these findings, periodic assessment of the fast bowler's shoulder is recommended.

Assessment of range of motion will indicate the presence of tightness during shoulder rotation. A bilateral comparison may reveal the presence of adaptations between the dominant and non-dominant shoulders. Assessment of muscle strength will reveal strength asymmetries of the shoulder rotators and based on the findings, and they can be strengthened. Also, assessment of the glenohumeral rhythm and scapular dyskinesis will indicate weakness of the scapular stabilisers and may help detect adaptations due to repetitive bowling or throwing.

The fourth study of this thesis assessed fast bowlers with shoulder pain. Although there were no statistically significant differences, the study revealed that internal rotators were slightly stronger than external rotators and dominant arm was slightly stronger than the non-dominant arm. But, no significant change was observed between injured and uninjured fast bowlers. The reason for the indifference may also be that the fast bowlers with shoulder pain were at early stages of injury and no structural adaptation had taken place. The fast bowlers in the study continued to play cricket regardless of shoulder pain. Maybe there will be a large strength, and ROM difference observed if the shoulder pain was severe enough for the fast bowlers to skip training. Due to the considerable variance and smaller sample size, the significance of a decreased range of motion and muscle strength could not be established in the fourth study. Therefore, it is recommended as a future research direction, to recruit a large cohort of fast bowlers with shoulder pain and compare the rotational range of motion and rotator cuff muscle strength with healthy fast bowlers.

4.1.7 Pathomechanism leading to chronic shoulder pain

Upon analysis of the study results, it is understood that cricket-related shoulder injuries are mostly due to overuse. Also, when comparing the findings of the studies with existing shoulder injury research, it is realised that subacromial space pathology has a higher prevalence amongst overhead throwing sports athletes in comparison to any other shoulder pathology. Encroachment of the subacromial space and compression of its tissues due to various intrinsic and extrinsic factors may be the pathomechanism for injury (Lopes et al.,

2015). Increasing the rotator cuff muscle strength to maintain glenohumeral stability is suggested as the best approach to reduce subacromial space pathology.

Rotator cuff muscle performs a dual function. It maintains the glenohumeral joint stability by resisting humeral head translation and fixing it in the glenoid cavity (Lopes et al., 2015). The rotator cuff also produces force to abduct and rotate the humerus on the glenohumeral joint. Hence, weakness and fatigue of the rotator cuff will affect glenohumeral movement and stability. Initial stages of repetitive and strenuous glenohumeral movement will cause fatigue to the rotator cuff and reduce the force produced during cricket bowling or throwing (Saw et al., 2011). If the bowling and throwing workload keeps increasing without enough rest for the rotator cuff muscle tissue to recover, it may lead to microtrauma at the rotator cuff muscles' musculotendinous junction, and bowler might experience slight discomfort (Steuri et al., 2017). There may also be an early onset of fatigue during bowling or throwing training. This may be termed as phase 1 of subacromial space pathology. As the trauma caused to the muscle is very mild, the pain severity also might be very low. At this stage, the fast bowler may not miss training or matches. Medical advice may not be sought at this stage due to the low severity of pain (Ranson and Gregory, 2007). This also would mean that it may not be recorded in the player injury report form and possibly would not be picked up in cricket injury surveillance reports.

If the cricketer continues to bowl and throw at the same threshold or increase the workload the chances to cause further damage to the shoulder rotator's musculotendinous junction are higher. Often elite cricketers during a playing season may play first-class matches and suddenly transition to T20 formats. There may also be a sudden increase in throwing sessions or bowling in nets. Playing multiple match formats, combined with training and gym sessions will cause a spike in workload. Spikes in workload may further damage the tissues of the musculotendinous junction and cause accumulation of oedema and haemorrhage in the muscle (Shim and Niederbracht, 2014). At this stage, the fast bowler may complain of slightly higher pain. This stage may be termed phase 2 of subacromial impingement.

Due to the presence of oedema and haemorrhage, inflammation sets in the rotator cuff and may lead to a reduction of the subacromial space (Bigliani and Levine, 1997). Reduction in subacromial space means, there may be further mechanical compression of the rotator cuff tendons under the acromion process, especially during bowling abduction movements

(MacDonald et al., 2000). As the supraspinatus tendon passes below the acromion process, it gets impinged during bowling-abduction, and this further irritates the tendon. This may reduce the strength of the supraspinatus muscle and further affects its function. Because supraspinatus is the main abductor muscle, the fast bowler might complain of pain during abduction. Also, as the supraspinatus prevents translation of the humerus, inflammation to the tendon may affect its strength in resisting the translation (MacDonald et al., 2000). In addition to this, the infraspinatus also passes below the acromion process, and compression of its tendon may affect external rotation. The infraspinatus functions to compress the humerus against the glenoid cavity. If inflammation sets in the infraspinatus tendon, it becomes weak and cannot provide humeral compression (Bigliani and Levine, 1997).

Furthermore, if the bowling and throwing workload is not reduced, secondary trauma to the rotator cuff tendons occurs due to repetitive impingement. This repetitive impingement, combined with low rest periods between training sessions, may also affect the subacromial bursa and cause oedema. The repetitive impingement may cause fibrosis of the supraspinatus and infraspinatus muscle (Page, 2011). Fibrosis and inflammation of the tendons will affect the supraspinatus and infraspinatus strength and compromise their function in stabilising the humerus (MacDonald et al., 2000). The subscapularis is a large and strong muscle producing internal rotation during bowling and throwing movement. The weaker external rotators have to eccentrically contract to decelerate during the rotational movements (Muraki et al., 2012). Due to inflammation and fibrosis of the external rotators, they may become weaker and cannot assist in the deceleration during rotational movements (Michener et al., 2003). At this stage, the fast bowler may complain of pain affecting their bowling performance, and it might cause them to be unavailable for selection due to shoulder injury. This will be recorded in the player injury report form and will be reported in injury surveillances. This stage may be termed as phase 3 of subacromial impingement.

If medical attention is not sought at this phase, further damage could occur to the rotator cuff tendons due to increased fibrosis and inflammation (Muraki et al., 2012). This will weaken the external rotators and cause a reduction in external rotation range of motion. A combination of conditions such as subacromial impingement, rotator cuff tendinopathy and subacromial bursitis may be present upon examination of the shoulder joint (Michener et al., 2003). Hence, to prevent all these phases of impingement, any early report of even mild

shoulder pain should be noted, and the shoulder rotators muscle strength should be assessed as a preventative approach (Whiteley and Ocegüera, 2016).

4.1.8 Three strategies for reducing fast bowler's shoulder injuries

Fast bowler's shoulder injuries cannot be totally prevented, but injury risk could certainly be minimised (Forrest et al., 2018). If stress is placed on a tissue more than its tolerable limit, it eventually leads to musculoskeletal trauma. Hence, injury prevention strategies should be aimed at:

1. Identifying players at injury risk and prepare them ahead of the playing season
2. Finding methods to reduce the chronic stress placed on the injury-prone tissues
3. Finding methods to increase the stress tolerance of the tissues most likely to be injured

The first step towards cricket injury prevention relies on identifying the players at increased injury risk. Screening players has to be done ahead of the playing season so that, appropriate training could be implemented to ensure the player has an injury-free playing season (Bahr and Krosshaug, 2005). In order to identify players at higher shoulder injury risk, musculoskeletal assessment and pre-participation shoulder screening should be implemented (Berckmans et al., 2017). The various intrinsic factors such as deficits in range of motion and muscle tightness must be included in the periodic assessment (Olivier et al., 2016b). Assessments of shoulder internal and external range of motion, glenohumeral internal rotation deficit, scapulohumeral rhythm and rotator cuff muscle strength must be undertaken. Tests specific to the shoulder is essential for every player in the squad, as every player has to throw during fielding, but more importantly for the fast bowler as the musculoskeletal stress is higher for the fast bowler's shoulder tissue (Gregory et al., 2004a).

Secondly, methods to reduce the chronic stress placed on the fast bowler's shoulder tissues should be sought. This relies solely on workload monitoring. Accurate logging of bowling and throwing workload is essential for injury prevention. Adequate rest between training bowling spells and matches are necessary for the tissues to recover from the stress (Saw et al., 2011). Most cricket boards have recommended bowling and throwing workload guidelines. Following these guidelines based on the age and playing-level is vital for shoulder injury prevention, as this will ensure that the shoulder joint tissues subjected to repetitive stress are within the tolerable limits.

Thirdly, methods to increase the stress tolerance of the tissues most likely to be injured should be sought. This is a very important aspect of shoulder injury prevention (Silva et al., 2018). Glenohumeral joint stability is reliant on the tissue strength of its static and dynamic stabilisers. Any undue stress on these tissues leading to their trauma is likely to cause instability in the joint. It is understood that conditioned tissues are more elastic in nature and can adapt to stress placed through them. Not all tissues could be conditioned to adapt to the stress placed upon them, for instance, the glenohumeral joint ligaments are far less elastic than the rotator cuff muscle (Beitzel et al., 2016). Hence, to reduce risk of an injury to the joint, the stress placed on the glenohumeral ligaments must be reduced, whereas to reduce the risk of injury to the rotator cuff muscle, methods to increase its cross-sectional area and force production/absorption qualities must be employed so that the muscle tissue could adapt and tolerate more stress.

4.1.9 Role of Indian clubbells in strengthening the rotator cuff muscles and preventing shoulder injuries

Two main steps are necessary to prevent shoulder impingement conditions. First, allowing enough rest periods between training sessions for the rotator cuff muscles to recover. Second, exercises to strengthen the external rotators even before injury onset occurs is recommended. This strengthening of the external rotators may prevent humeral translation and subacromial impingement. Manipulating cricket training's frequency, intensity and duration are essential for the rotator cuff tendons to adapt to the progressive workload and be prepared for spikes in bowling between match formats. Insufficient workload will not prepare the muscles to handle spikes in bowling and will cause acute trauma. Also allowing enough rest periods is essential so that the muscles can recover from the excessive overload.

Strengthening the rotator cuff is suggested as a preventative approach to reduce subacromial space pathologies for the fast bowler (Shire et al., 2017). In study 5, it was found that the internal rotators of the Indian clubbell group participants increased their strength significantly, while there was not a significant change observed on the external rotators. As the internal rotators are stronger than the external rotators by nature, injury prevention strategies must be targeted towards the external rotators. Research suggests that the superior-anterior translation of the humerus is much more common than posterior humeral translation (Taniguchi et al., 2017). Also, subacromial impingement is much more common than

posterior shoulder impingement (Cowderoy et al., 2009). Therefore, in order to prevent superior-anterior translation, it is essential to increase the external rotator muscle strength. Both the supraspinatus and the infraspinatus should be strengthened.

In study 5, the Indian clubbell group participants underwent an exercise programme lasting six weeks. The exercise programme involved a progression from 500gms to 1kg clubbells after the third week. If the same exercise programme is used for a more extended period, a 500gms increase can be done every three weeks. Any sudden increase in clubbell weights or starting the exercises directly with clubbells weighing more than 1kg is not recommended. This is suggested to ensure familiarity with the exercises and to prevent any injury due to the exercise itself. As the clubbells are held using hands and are moved against and with gravity like a pendulum, there is enough resistance provided by gravity and the clubbells.

The six-week exercise programme included multiple movements such as shoulder circumduction, flexion, extension, abduction, adduction, internal and external rotation. All these movements are used during the fast bowling action. The ability to use the Indian clubbells in all planes of movement along with resistance is the main advantage of the Indian clubbells in comparison to other exercise equipment. Also, dumbbells, barbells and elastic resistance bands could only be used in one plane at a time, and resistance cannot be applied in all directions.

Progressively loading the rotator cuff muscles using Indian clubbells, with adequate recovery periods may increase the muscle cross-section and make them stronger. Stronger rotator cuff muscles could prevent humeral translation and increase glenohumeral stability. Therefore, it is recommended that Indian clubbell exercises be included as part of an injury prevention programme for fast bowlers.

Comparing the findings of this thesis with existing literature, the following pathomechanisms and modifications are suggested:

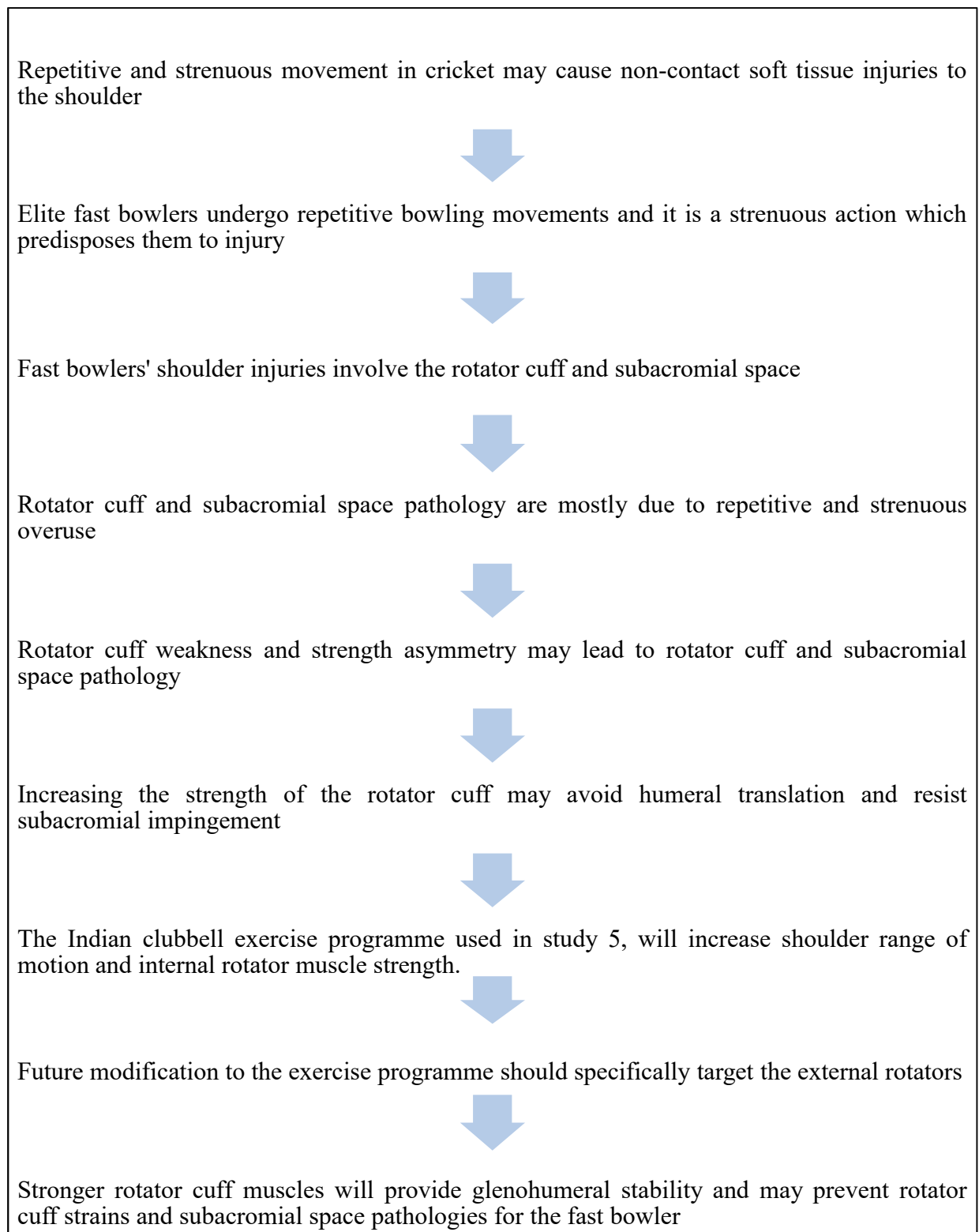


Figure 3.2. Shoulder injury pathomechanism and suggestions for prevention

CHAPTER FIVE

Conclusion

5.1 Application strategies for fast bowler's shoulder injury prevention

This thesis was based on van Mechelen's sports injury prevention model, and the first three stages of the model have been applied in all studies of this thesis.

Injury prevention is essential for the health of the cricketer and the team's performance. The key to injury prevention is the identification of cricketers at risk. The most effective way to identify the cricketers at risk is by administering injury surveillance. The first three studies quantified cricket-related shoulder injuries through various methods, but certain modifications are needed to conduct quality injury surveillance. Clearly defined injury definitions are necessary, and these injury definitions should include non-time loss injuries occurring during both training and matches. Long term prospective injury surveillance is the best way to capture and quantify data. All injury-specific diagnosis must be recorded and analysed so that, the aetiology of the injuries can be identified based on the injury's medical diagnoses.

In addition to injury surveillance, monitoring bowling and throwing workload are essential to understand injury aetiology. A combination of injury surveillance and workload monitoring may help understand the intrinsic and extrinsic causes of an injury. Separate logging of balls thrown and balls bowled must be recorded. This is required so that the cause of shoulder injury can be differentiated and identified. Age-specific bowling and throwing workload must be researched and recommended across all levels of cricket. Appropriate rest periods following training and matches must be ensured for optimal recovery of the shoulder rotators. Regional cricket associations should ensure that these recommendations are followed across all levels of cricket.

Exercise-based shoulder injury prevention programmes must be recommended across all levels of cricket. Indian clubbell exercises, with the focus of strengthening the external rotators, should be introduced. Indian clubbell exercises with weight progression should be done at least twice per week during both off-season and playing season. The introduced preventive measures also need to be validated. It is recommended that the Indian clubbell exercise programme, should be implemented across a large sample size throughout a playing season, along with prospective injury surveillance. Only by conducting injury surveillance,

the true effect of these exercises in preventing shoulder injuries could be established, as recommended by the fourth stage of van Mechelen's sports injury prevention model (van Mechelen et al., 1992).

5.2 Recommendations for musculoskeletal shoulder screening

Several validated tests are available to score shoulder pain like the Shoulder Pain and Disability Index (Roach et al., 1991) and Disabilities of the Arm Shoulder and Hand (Hudak et al., 1996). These tests are used only when mild symptoms or discomfort arises around the shoulder area. A prospective, periodic, objective assessment, regardless of symptoms, will help monitor the shoulder adaptations due to the demands of cricket.

Hence, periodic musculoskeletal screening of cricketers should include:

Internal and external rotators muscle strength assessment (Donatelli et al., 2000).

The rotator cuff muscle strength is essential for glenohumeral stability. Any fatigue, weakness or strain to the rotator cuff will affect the movement of the joint. Anatomical adaptations due to frequent bowling and throwing may be initially observed only on the muscles. Therefore, any early changes in muscle asymmetry have to be detected. Pre-season assessment of the external and internal rotator muscle strength may expose cricketers with weaker external rotators. Those identified cricketers can then undertake external rotator strengthening exercises. Monthly assessment of rotator cuff muscle strength, throughout the playing season may also help detect weakness, fatigue or early signs of rotator cuff strain. This will also ensure that the bowling and throwing workload of cricketers at heightened injury risk is reduced or managed effectively.

Glenohumeral rotational range of motion assessment (Muir et al., 2010).

Range of motion is the direction and distance a joint can move. Assessment of range of motion will indicate the presence of any functional restrictions in the joint. The available shoulder range of motion while doing flexion, extension and abduction movements are large in comparison to its rotational movements. While assessment of all shoulder range of motion is important, measurement of the rotational range of motion is the best indicator for detecting glenohumeral pathology. As glenohumeral rotation involves the rotator cuff muscle, shoulder

capsule and glenohumeral ligaments, any structural adaptation to these soft tissues due to the demands of throwing and bowling will cause changes to the available rotational range of motion. Therefore, including assessment of the rotational range of motion during pre-season screening will identify cricketers at increased risk of a shoulder injury. Screening cricketer's rotational range of motion once a month during the entire playing season may help monitor any soft tissue adaptations due to the demands of cricket. This will help undertake preventative measures.

Scapular dyskinesis assessment (Uhl et al., 2009)

Scapular dyskinesis is a common clinical presentation amongst overhead athletes with shoulder pain. The glenohumeral rhythm is the kinematic interaction between the humerus, scapula and the thoracic cage during shoulder abduction. During every ball bowled and thrown, the shoulder has to abduct. Repetitive frequent abduction has been shown to cause rotator cuff strain, weakness and fatigue to the scapula stabilising muscles. Tightness, weakness, asymmetry or fatigue of the rotator cuff and scapular stabilising muscles will cause changes to the scapulohumeral rhythm. Bilateral comparison of the rhythm and looking for any tilting or winging of the scapula may indicate the presence of any deviations. Scapular dyskinesis assessment must be included during preseason shoulder screening. This screening will identify cricketers with any existing shoulder asymmetry and initiate prevention methods. Assessing scapular dyskinesis for cricketers once a month, during the playing season is recommended to monitor any scapular muscle tightness or weakness caused by repetitive throwing and bowling.

5.3 Limitations of the thesis

Although the studies of this thesis were based on van Mechelen's sports injury prevention model, the final stage of the model could not be included in this thesis. The first three studies quantified shoulder injuries and established injury aetiology. The fourth study investigated injured shoulders. The final study introduced an exercise programme which may prevent shoulder injuries. Revisiting and quantifying shoulder injury prevalence amongst the Indian clubbell group participants throughout the playing season will take a longer study period. Implementing the Indian clubbell exercise programme to a larger sample size and waiting for injuries to occur will also consume a long time. This will be beyond the timeframe of this thesis. Therefore, it is acknowledged as a limitation.

The ACC study data did not record injury-specific medical diagnosis information. Because of this, the most common shoulder injury diagnosis could not be identified. If this information was available, injury prevention strategies could be implemented based on medical diagnoses. Also, the ACC data did not record cricket-specific activity during injury onset. If this information was available, it would be easier to identify the most injury-prone cricket activity. Hence, the lack of all the above-mentioned information in the ACC data is acknowledged as a limitation to this study.

The 2015 CWC study, was conducted to record the injury prevalence during the cricket world cup. This study relied solely on the media reports, although some players were benched during the tournament, information regarding the reason for not playing matches was not always available. As all injury data were obtained from media releases, a likely limitation of this study is biased media reporting. Injury reports for newer players, particularly those from lower-ranked teams, may have been considered less newsworthy, and not reported. Another limitation of this study was the reluctance of some lower-ranked teams to update information on their cricket board websites regarding their players' statistics and injuries, due to which many injuries may not have been recorded. Multiple injuries to the same players were not reported. Specific injury diagnoses information was not released to the media. One of the main limitations of this study was the unavailability of non-time loss injury data. These are all acknowledged as limitations to the 2015 CWC study. This method of injury surveillance

during international tournaments is recommended only if official injury surveillance is not scheduled or permitted.

The NZ elite fast bowlers' injury study could be influenced by the data collection method. The retrospective data collection method was implemented to collect data directly from the players with a new injury definition in which any experienced musculoskeletal pain could be reported as an injury and not just injuries which caused matches to be missed. However, it is acknowledged that retrospective surveys may not accurately report injury prevalence as it relies on the participant's response and lacks a physician's verification. However, as the participants in the current study were professional cricketers who keep training diaries, I believe the data collected may contain a higher degree of accuracy and reliability. I acknowledge that retrospective injury surveillance methods could also have recall bias, where some injury information could have been lost due to failure to recall the injury event, and also the tendency to over-report the severity of the past injuries with respect to the days missed due to an injury.

The fourth study assessed shoulder ROM and muscle strength between injured and uninjured fast bowlers. The results might have demonstrated a statistically significant difference between groups if more participants were recruited. Because specialist fast bowlers from only four clubs agreed to participate in the study, more participants were not available locally. Due to this low number of participants, there was a considerable variation in the standard deviation of the variables such as range of motion and isometric muscle strength. This variation affected the results, and statistical significance could not be demonstrated, this is acknowledged as a limitation to the study. Also, the injured fast bowlers had only moderate level of shoulder pain and continued to play cricket, if fast bowlers who miss training due to more severe shoulder pain were recruited, they might display a larger difference in ROM and muscle strength.

5.4 Summary of key findings

Study 1: The age-standardised cricket-related injury incidence for the nationwide NZ male population increased by 45% with 2771 injuries per 10000 people in the year 2005 to 3935 injuries per 10000 people in the year 2016. In comparison to all other body areas, the shoulder area experienced the highest increase in injury prevalence by 86% with 468 injuries occurring in the year 2005 to 864 injuries occurring in 2016. The main causes of non-contact soft tissue injuries to the shoulder were repetitive and strenuous movement.

Study 2: During the 2015 ICC CWC, fast bowlers experienced the highest injury prevalence, and bowling in matches was the most common activity at injury onset.

Study 3: Shoulder injuries had the fourth highest prevalence amongst NZC domestic fast bowlers during the playing season of 2016-2017. Fifty percent of all acute injuries occurred during bowling. Pathology related to the rotator cuff and subacromial space was the most common shoulder diagnosis.

Study 4: The shoulder joint's rotational ROM and rotator cuff muscle strength was slightly lower among fast bowlers with shoulder pain in comparison to uninjured fast bowlers.

Study 5: Cricket fast bowlers involved in a six-week Indian clubbells strength programme increased their bilateral rotational range of motion and internal rotators muscle strength.

5.5 Future research directions

Future research should compare between throwing workload and bowling workload. This comparison should be associated with shoulder injury incidence. This will find out which activity predisposes the shoulder to more injuries.

Even though the importance of cricket injury surveillance is acknowledged, there was no official injury surveillance during from the 2015 Cricket World Cup. The media-based injury report from 2015 CWC has highlighted the extent of injury prevalence among players in the tournament. Therefore, undertaking prospective injury surveillance during these multinational tournaments is advocated.

The Indian clubbells exercises have been effective in increasing the strength of the internal rotators. However, to prove its advantageous effects, conducting a comparative study with resistance bands aimed at strengthening the external rotators is suggested.

The effect of the Indian clubbells exercises on bowling and throwing performance has to be researched. Future studies could investigate the effects of increasing rotator cuff strength through the Indian clubbell exercises and its impact on bowling speed and accuracy.

In order to establish the Indian clubbell exercises as an effective shoulder injury prevention programme for cricketers, it is suggested that randomised control trials with Indian clubbells exercises should be carried out on cricketers from the start of the pre-season to the end of the playing season. Also, a correlative analysis should be undertaken amongst the participating cohort on their shoulder injury incidence and the usage of the Indian clubbell exercises.

5.6 Conclusive summary

In order to implement a cricket injury prevention programme across all levels of cricket, longitudinal injury surveillance is recommended across all levels of cricket. One of the most injury-prone body areas due to cricket participation was the shoulder. A healthy shoulder is vital for executing the fast bowling action. To prevent and reduce the incidence of shoulder injuries, it is necessary to conduct regular shoulder screening as this will help detect early structural adaptations occurring in the joint due to overuse. The soft tissue most affected due to overuse in the shoulder in the rotator cuff muscle. Repetitive and strenuous movement may

cause overuse injuries and affect the rotator cuff muscle. Providing adequate recovery periods aids to heal the shoulder's soft tissue after the repetitive strenuous movement and strengthening the rotator cuff contributes to glenohumeral joint stability, and this may help reduce the incidence of shoulder injuries. To increase the rotator cuff strength, the Indian clubbell exercise programme may be used. Stronger dynamic shoulder stabilisers will provide glenohumeral stability during bowling or throwing actions, and this may reduce the risk of shoulder injuries.

References

- AGINSKY, K. D., LATEGAN, L. & STRETCH, R. A. 2004. Shoulder injuries in provincial male fast bowlers - predisposing factors. *South African Journal of Sports Medicine*, 16, 25.
- ALI, M. A., SUNDARAJ, K., AHMAD, R. B., AHAMED, N. U., ISLAM, M. A. & SUNDARAJ, S. 2016. EMG activities of the three heads of the triceps brachii muscle during cricket bowling. *Journal of Mechanics in Medicine and Biology*, 16, 1650075.
- ALMEIDA, G. P. L., SILVEIRA, P. F., ROSSETO, N. P., BARBOSA, G., EJNISMAN, B. & COHEN, M. 2013. Glenohumeral range of motion in handball players with and without throwing-related shoulder pain. *Journal of Shoulder And Elbow Surgery*, 22, 602-607.
- ALPERT, S. W., PINK, M. M., JOBE, F. W., MCMAHON, P. J. & MATHIYAKOM, W. 2000. Electromyographic analysis of deltoid and rotator cuff function under varying loads and speeds. *Journal of Shoulder Elbow and Surgery*, 9, 47-58.
- ANDARY, J. L. & PETERSEN, S. A. 2002. The vascular anatomy of the glenohumeral capsule and ligaments: an anatomic study. *The Journal of Bone and Joint Surgery. American volume*, 84-A, 2258-2265.
- ANDERSSON, S. H., BAHR, R., CLARSEN, B. & MYKLEBUST, G. 2017. Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players. *British Journal of Sports Medicine*, 51, 1073-1080.
- ARORA, M., PAOLONI, J. A., KANDWAL, P. & DIWAN, A. D. 2014. Are fast-bowlers prone to back injuries? Prevalence of lumbar spine injuries in fast-bowlers: Review of MRI-based studies. *Asian Journal of Sports Medicine*, 5, e24291-e24291.
- ARORA, M., SHETTY, S. H. & DHILLON, M. S. 2015. The shoulder in cricket: What's causing all the painful shoulders? *Journal of Arthroscopy and Joint Surgery*, 2, 57-61.
- BAHR, R. & KROSSHAUG, T. 2005. Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine*, 39, 324-329.

- BAYIOS, I. A., ANASTASOPOULOU, E. M., SIOUDRIS, D. S. & BOUDOLOS, K. D. 2001. Relationship between isokinetic strength of the internal and external shoulder rotators and ball velocity in team handball. *The Journal of Sports Medicine and Physical Fitness*, 41, 229.
- BAYNE, H., CAMPBELL, A., ELLIOTT, B. & ALDERSON, J. 2011. The relationship between shoulder counter-rotation and lumbar mechanics during fast bowling. *Journal of Science and Medicine in Sport*, 19, 117-122.
- BAYNE, H., ELLIOTT, B., CAMPBELL, A. & ALDERSON, J. 2016. Lumbar load in adolescent fast bowlers: A prospective injury study. *Journal of Science and Medicine in Sport*, 19, 117-122.
- BEITZEL, K., ZANDT, J. F., BUCHMANN, S., BEITZEL, K. I., SCHWIRTZ, A., IMHOFF, A. B. & BRUCKER, P. U. 2016. Structural and biomechanical changes in shoulders of junior javelin throwers: a comprehensive evaluation as a proof of concept for a preventive exercise protocol. *Knee Surgery, Sports Traumatology, Arthroscopy*, 24, 1931-1942.
- BELL-JENJE, T.C & GRAY, J. 2005. Incidence, nature and risk factors in shoulder injuries of national academy cricket players over 5 years - a retrospective study. *South African Journal of Sports Medicine*, 17.
- BERCKMANS, K., MAENHOUT, A. G., MATTHIJS, L., PIETERS, L., CASTELEIN, B. & COOLS, A. M. 2017. The isokinetic rotator cuff strength ratios in overhead athletes: Assessment and exercise effect. *Physical Therapy in Sport*, 27, 65-75.
- BIGLIANI, L. U. & LEVINE, W. N. 1997. Subacromial impingement syndrome. *Journal of Bone and Joint Surgery America*, 79, 1854-68.
- BIZZINI, M. & DVORAK, J. 2015. FIFA 11+: an effective programme to prevent football injuries in various player groups worldwide-a narrative review. *British Journal Of Sports Medicine*, 49, 577-579.
- BLUME, C., WANG-PRICE, S., TRUDELLE-JACKSON, E. & ORTIZ, A. 2015. Comparison of eccentric and concentric exercise interventions in adults with subacromial impingement syndrome. *International Journal of Sports Physical Therapy*, 10, 441.

- BOETTCHER, C. E., CATHERS, I. & GINN, K. A. 2010. The role of shoulder muscles is task specific. *Journal of Science and Medicine in Sport*, 13, 651-656.
- BOILEAU, P., MCCLELLAND, J. W. B. & RUMIAN, A. P. 2014. Massive irreparable rotator cuff tears: how to rebalance the cuff-deficient shoulder. *Instructional Course Lectures*, 63, 71.
- BOND, S. & CLEAVER, D. 2010. *Shane Bond: looking back*, Auckland, N.Z, Hodder Moa.
- BOON, A. J. & SMITH, J. 2000. Manual scapular stabilization: its effect on shoulder rotational range of motion. *Archives of Physical Medicine and Rehabilitation*, 81, 978-983.
- BORSA, P. A., LAUDNER, K. G. & SAUERS, E. L. 2008. Mobility and stability adaptations in the shoulder of the overhead athlete. *Sports Medicine*, 38, 17-36.
- BOURNE, M. N., TIMMINS, R. G., OPAR, D. A., PIZZARI, T., RUDDY, J. D., SIMS, C., WILLIAMS, M. D. & SHIELD, A. J. 2018. An evidence-based framework for strengthening exercises to prevent hamstring injury. *Sports Medicine*, 48, 251-267.
- BRAMAN, J. P., ZHAO, K. D., LAWRENCE, R. L., HARRISON, A. K. & LUDEWIG, P. M. 2014. Shoulder impingement revisited: evolution of diagnostic understanding in orthopedic surgery and physical therapy. *Medical Biology Engineering and Computing*, 52, 211-9.
- BROSSMANN, J., PREIDLER, K., PEDOWITZ, R., WHITE, L., TRUDELL, D. & RESNICK, D. 1996. Shoulder impingement syndrome: influence of shoulder position on rotator cuff impingement--an anatomic study. *American Journal of Gerontology*, 167, 1511-1515.
- BRUKNER, P. 2012. *Bruckner & Khan's Clinical Sports Medicine*, McGraw-Hill North Ryde.
- BURKHART, S. S., MORGAN, C. D. & KIBLER, W. B. 2003. The disabled throwing shoulder: spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy : The Journal of Arthroscopic & Related Surgery : Journal Article*, 19, 641.

- ÇALIŞ, M., AKGÜN, K., BIRTANE, M., KARACAN, I., ÇALIŞ, H. & TÜZÜN, F. 2000. Diagnostic values of clinical diagnostic tests in subacromial impingement syndrome. *Annals of the Rheumatic Diseases*, 59, 44-47.
- CHAMBERS, C. 2011. *A history of cricket*, Newtown, N.S.W., Black Dog Books, an imprint of Walker Books Australia.
- CHRISTIE, C. J. A. (2012). *The physical demands of batting and fast bowling in cricket* (pp. 978-953). ISBN.
- CHARLES, A. R. R. & A, C. 2009. *The Shoulder E-Book: Expert Consult - Online and Print*, US, Saunders.
- CLABBERS, K. M., KELLY, J. D., BADER, D., EAGER, M., IMHAUSER, C., SIEGLER, S. & MOYER, R. A. 2007. Effect of posterior capsule tightness on glenohumeral translation in the late-cocking phase of pitching. *Journal of Sport Rehabilitation*, 16, 41-49.
- CLARKE, M., DA MHUIRCHEARTAIGH, N., WALSH, G., WALSH, J. & MELDRUM, D. 2011. Intra-tester and inter-tester reliability of the MicroFET 3 hand-held dynamometer. *Physiotherapy Practice and Research*, 32, 13-18.
- CLARSEN, B., BAHR, R., ANDERSSON, S. H., MUNK, R. & MYKLEBUST, G. 2014. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *British Journal of Sports Medicine*, 48, 1327-33.
- COOK, E. E., GRAY, V. L., SAVINAR-NOGUE, E. & MEDEIROS, J. 1987. Shoulder antagonistic strength ratios: a comparison between college-level baseball pitchers and nonpitchers. *The Journal of Orthopaedic and Sports Physical Therapy*, 8, 451.
- COPELAND, S. 1993. Throwing injuries of the shoulder. *British Journal of Sports Medicine*, 27, 221-227.
- COWDEROY, G. A., LISLE, D. A. & O'CONNELL, P. T. 2009. Overuse and impingement syndromes of the shoulder in the athlete. *Magnetic Resonance Imaging Clinics of North America Journal Article*, 17, 577.

- CRICKET WORLD CUP RESULTS & ATTENDANCES. (n.d.). Retrieved from https://www.austadiums.com/sport/comp_results.php?sid=31
- CRICKET, N. Z. (n.d.). Archive. Retrieved from <https://www.nzc.nz/archive>
- CUÉLLAR, R., RUIZ-IBÁN, M. A. & CUÉLLAR, A. 2017. Anatomy and biomechanics of the unstable shoulder. *The Open Orthopaedics Journal*, 11, 919-933.
- DAVID, G., MAGAREY, M., JONES, M., DVIR, Z., TÜRKER, K. & SHARPE, M. 2000a. EMG and strength correlates of selected shoulder muscles during rotations of the glenohumeral joint. *Clinical Biomechanics*, 15, 95-102.
- DAVID, G., MAGAREY, M. E., JONES, M. A., DVIR, Z., TURKER, K. S. & SHARPE, M. 2000b. EMG and strength correlates of selected shoulder muscles during rotations of the glenohumeral joint. *Clinical Biomechanics* (Bristol, Avon), 15, 95-102.
- DAVIES, R., DU RANDT, R., VENTER, D. & STRETCH, R. 2008. Cricket: Nature and incidence of fast-bowling injuries at an elite, junior level and associated risk factors. *South African Journal of Sports Medicine*, 20, 115-118.
- DEFRANCO, M. J. & COLE, B. J. 2009. Current perspectives on rotator cuff anatomy. *Arthroscopy : The Journal Of Arthroscopic & Related Surgery*, 25, 305.
- DENNIS, R. J., FINCH, C. F. & FARHART, P. J. 2005. Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *British Journal of Sports Medicine*, 39, 843.
- DEPALMA, M. J. & JOHNSON, E. W. 2003. Detecting and treating shoulder impingement syndrome: the role of scapulothoracic dyskinesis. *The Physician and Sports Medicine*, 31, 25.
- DHILLON, M. S., GARG, B., SONI, R. K., DHILLON, H. & PRABHAKAR, S. 2012. Nature and incidence of upper limb injuries in professional cricket players a prospective observation. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology : SMARTT*, 4, 42-42.
- DONATELLI, R., ELLENBECKER, T. S., EKEDAHL, S. R., WILKES, J. S., KOCHER, K. & ADAM, J. 2000. Assessment of shoulder strength in professional baseball pitchers. *Jounral of Orthopedic Sports Physical Therapy*, 30, 544-51.

- DUHIG, S., SHIELD, A. J., OPAR, D., GABBETT, T. J., FERGUSON, C. & WILLIAMS, M. 2016. Effect of high-speed running on hamstring strain injury risk. *British Journal of Sports Medicine*, 50, 1536-1540.
- EDWARDS, P., EBERT, J., JOSS, B., BHABRA, G., ACKLAND, T. & WANG, A. 2016. Exercise rehabilitation in the non-operative management of rotator cuff tears: a review of the literature. *International Journal of Sports Physical Therapy*, 11, 279-301.
- ELLIOTT, B., WALLIS, R., SAKURAI, S., LLOYD, D. & BESIER, T. 2002. The measurement of shoulder alignment in cricket fast bowling. *Journal of Sports Sciences*, 20, 507-510.
- ESCAMILLA, R. F. & ANDREWS, J. R. 2009. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. *Sports Medicine*, 39, 569-590.
- FAUDE, O., MEYER, T., FEDERSPIEL, B. & KINDERMANN, W. 2009. Injuries in Elite German Football - a Media-based Analysis. *Deutsche Zeitschrift für Sportmedizin*, 60, 139-144
- FERDINANDS, R., KERSTING, U. G., MARSHALL, R. N. & STUELCKEN, M. 2010. Distribution of modern cricket bowling actions in New Zealand. *European Journal of Sport Science*, 10, 179-190.
- FINCH, C., ELLIOTT, B., HAMER, P. & STEVENSON, M. 2003. The Western Australian sports injury study: the magnitude and key risk and protective factors for sports injury at the population level in Australia have been established. *British Journal of Sports Medicine*, 37, 380.
- FLATOW, E. L., SOSLOWSKY, L. J., TICKER, J. B., PAWLUK, R. J., HEPLER, M., ARK, J., MOW, V. C. & BIGLIANI, L. U. 1994. Excursion of the rotator cuff under the acromion: patterns of subacromial contact. *The American Journal of Sports Medicine*, 22, 779-788.
- FORREST, M. R. L., SCOTT, B. R., HEBERT, J. J. & DEMPSEY, A. R. 2018. Injury prevention strategies for adolescent cricket pace bowlers. *Sports Medicine*, 48, 2449-2461.

- FROST, W. L. & CHALMERS, D. J. 2014. Injury in elite New Zealand cricketers 2002-2008: descriptive epidemiology. *British Journal of Sports Medicine*, 48, 1002-1007.
- FRUSH, T. J. & LINDENFELD, T. N. 2009. Peri-epiphyseal and Overuse Injuries in Adolescent Athletes. *Sports Health*, 1, 201-211.
- FU, F. H., HARNER, C. D. & KLEIN, A. H. 1991. Shoulder impingement syndrome. A critical review. *Clinical Orthopedics and Related Research*, 162-73.
- GABBETT, T. J. 2016. The training—injury prevention paradox: should athletes be training smarter and harder? *British Journal of Sports Medicine*, 50, 273-280.
- GILLOOLY, J. J., CHIDAMBARAM, R. & MOK, D. 2010. The lateral Jobe test: A more reliable method of diagnosing rotator cuff tears. *International Journal of Shoulder Surgery*, 4, 41.
- GILES, K. & MUSA, I. 2008. A survey of glenohumeral joint rotational range and non-specific shoulder pain in elite cricketers. *Physical Therapy in Sport*, 9, 109-16.
- GLAZIER, P. S. & WHEAT, J. S. 2014. An Integrated Approach to the Biomechanics and Motor Control of Cricket Fast Bowling Techniques. *Sports Medicine*, 44, 25-36.
- GREGORY, P. L., BATT, M. E. & WALLACE, W. A. 2002. Comparing injuries of spin bowling with fast bowling in young cricketers. *Clinical Journal of Sports Medicine*, 12, 107-12.
- GREGORY, P. L., BATT, M. E. & WALLACE, W. A. 2004a. Is risk of fast bowling injury in cricketers greatest in those who bowl most? A cohort of young English fast bowlers. *British Journal of Sports Medicine*, 38, 125.
- GREGORY, P. L., BATT, M. E. & WALLACE, W. A. 2004b. Is risk of fast bowling injury in cricketers greatest in those who bowl most? A cohort of young English fast bowlers. *British Journal of Sports Medicine*, 38, 125-128.
- GREIG, M. & NAGY, P. 2017. Lumbar-and cervicothoracic-spine loading during a fast-bowling spell. *Journal of Sport Rehabilitation*, 26, 257-262.
- HALDER, A. M., ITOI, E. & AN, K. N. 2000. Anatomy and biomechanics of the shoulder. *Orthopedic Clinical North America*, 31, 159-76.

- HAREL, Y., OVERPECK, M. D., JONES, D. H., SCHEIDT, P. C., BIJUR, P. E., TRUMBLE, A. C. & ANDERSON, J. 1994. The effects of recall on estimating annual nonfatal injury rates for children and adolescents. *American Journal of Public Health*, 84, 599-605.
- HARPUT, G., GUNAY, H., TOPRAK, U., KAYA, T., COLAKOGLU, F. F. & BALTACI, G. 2016. Shoulder-rotator strength, range of motion, and acromiohumeral distance in asymptomatic adolescent volleyball attackers. *Journal of Athletic Training*, 51, 733-738.
- HASEBROOCK, A. W., BRINKMAN, J., FOSTER, L. & BOWENS, J. P. 2019. Management of primary anterior shoulder dislocations: a narrative review. *Sports Medicine - open*, 5, 31-31.
- HASHIGUCHI, H., IWASHITA, S., YONEDA, M. & TAKAI, S. 2018. Factors influencing outcomes of nonsurgical treatment for baseball players with SLAP lesion. *Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology*, 14, 6-9.
- HAWKINS, R. & KENNEDY, J. 1980. Impingement syndrome in athletes. *The American Journal of Sports Medicine*, 8, 151-158.
- HAYES, K., WALTON, J. R., SZOMOR, Z. L. & MURRELL, G. A. 2001. Reliability of five methods for assessing shoulder range of motion. *Australian Journal of Physiotherapy*, 47, 289-294.
- HAZARI, A., WARSI, M. & AGOURIS, I. 2016. Electromyography analysis of shoulder and wrist muscles in semi-professional cricket fast bowlers during bouncer and Yorker delivery. A cross-sectional comparative study. *International Journal of Physical Education, Sports and Health*, 3, 77-87.
- HODGINS, J. L., RUBENSTEIN, W., KOVACEVIC, D., PADAKI, A., JOBIN, C. M. & AHMAD, C. S. 2017. Pectoralis minor contracture in throwing shoulders of asymptomatic adolescent baseball players. *Orthopaedic Journal of Sports Medicine*, 5, 2325967117728041.

- HUANG, P., ANISSIPOUR, A., MCGEE, W. & LEMAK, L. 2016. Return-to-play recommendations after cervical, thoracic, and lumbar spine injuries: a comprehensive review. *Sports Health: A Multidisciplinary Approach*, 8, 19-25.
- HUDAK, P. L., AMADIO, P. C., BOMBARDIER, C., BEATON, D., COLE, D., DAVIS, A., HAWKER, G., KATZ, J. N., MAKELA, M. & MARX, R. G. 1996. Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder, and head). *American Journal of Industrial Medicine*, 29, 602-608.
- HULIN, B., GABBETT, T., BLANCH, P., CHAPMAN, P., BAILEY, D. & ORCHARD, J. 2013. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Journal of Science and Medicine in Sport*, 16, e95-e96.
- HULIN, B. T., GABBETT, T. J., BLANCH, P., CHAPMAN, P., BAILEY, D. & ORCHARD, J. W. 2014a. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *British Journal of Sports Medicine*, 48, 708-712.
- HULIN, B. T., GABBETT, T. J., BLANCH, P., CHAPMAN, P., BAILEY, D. & ORCHARD, J. W. 2014b. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *British Journal of Sports Medicine*, 48, 708-712.
- HURD, W. J., KAPLAN, K. M., EIATTRACHE, N. S., JOBE, F. W., MORREY, B. F. & KAUFMAN, K. R. 2011. A profile of glenohumeral internal and external rotation motion in the uninjured high school baseball pitcher, part I: motion. *Journal of Athletic Training*, 46, 282-288.
- IANIS. (2020, February 11). T20 cricket drives growth in associate countries: ICC - Times of India. Retrieved from <https://timesofindia.indiatimes.com/sports/cricket/news/t20-cricket-drives-growth-in-associate-countries-icc/articleshow/74082869.cms>
- JACOBSEN, P., WITVROUW, E., MUXART, P., TOL, J. L. & WHITELEY, R. 2016. A combination of initial and follow-up physiotherapist examination predicts physician-determined time to return to play after hamstring injury, with no added value of MRI. *British Journal of Sports Medicine*, 50, 431-439.

- JAIN, T. K. & SHARMA, N. K. 2014. The effectiveness of physiotherapeutic interventions in treatment of frozen shoulder/adhesive capsulitis: a systematic review. *Journal of Back Musculoskeletal Rehabilitation*, 27, 247-73.
- JOHNSON, L. 1992. Patterns of shoulder flexibility among college baseball players. *Journal of Athletic Training*, 27, 44-49.
- JOHNSON, M., FERREIRA, M. & HUSH, J. 2012. Lumbar vertebral stress injuries in fast bowlers: a review of prevalence and risk factors. *Physical Therapy in Sport*, 13, 45-52.
- KELLER, R. A., DE GIACOMO, A. F., NEUMANN, J. A., LIMPISVASTI, O. & TIBONE, J. E. 2018. Glenohumeral internal rotation deficit and risk of upper extremity injury in overhead athletes: a meta-analysis and systematic review. *Sports Health: A Multidisciplinary Approach*, 10, 125-132.
- KHONDKER, H. H. & ROBERTSON, R. 2018. Glocalization, consumption, and cricket: The Indian Premier League. *Journal of Consumer Culture*, 18, 279-297.
- KING, D. A., HUME, P. A., MILBURN, P. & GIANOTTI, S. 2009. Rugby league injuries in New Zealand: a review of 8 years of Accident Compensation Corporation injury entitlement claims and costs. *British Journal of Sports Medicine*, 43, 595-602.
- KING, M. A., WORTHINGTON, P. J. & RANSON, C. A. 2016. Does maximising ball speed in cricket fast bowling necessitate higher ground reaction forces? *Journal of Sports Sciences*, 34, 707-712.
- KIRCHHOFF, C. & IMHOFF, A. B. 2010. Posterosuperior and anterosuperior impingement of the shoulder in overhead athletes—evolving concepts. *International Orthopaedics*, 34, 1049-1058.
- KOUNTOURIS, A. 2017. Injuries in cricket: epidemiology and factors associated with lumbar spine injury in cricket fast bowlers. *Dissertation/Thesis*, Monash University.
- LAVER, L., LANDREAU, P., SEIL, R. & POPOVIC, N. 2018. Handball Sports Medicine : Basic Science, Injury Management and Return to Sport, Berlin, Heidelberg, Springer.

- LAXMI, R., PROSENJIT, P. & MOHD, D. S. 2015. Prevalence of shoulder injuries and altered scapular positioning in young elite cricketers. *International Journal of Sports Sciences and Fitness Journal Article*, 5, 130.
- LEARY, T. & WHITE, J. A. 2000. Acute injury incidence in professional county club cricket players (1985-1995). *British Journal of Sports Medicine*, 34, 145-147.
- LEWIS, J. S. & VALENTINE, R. E. 2007. The pectoralis minor length test: a study of the intra-rater reliability and diagnostic accuracy in subjects with and without shoulder symptoms. *Bio Med Central Musculoskeletal Disorders*, 8, 64-64.
- LIVE CRICKET SCORES & NEWS - ICC Cricket World Cup 2019. (n.d.). Retrieved from <https://www.cricketworldcup.com/>
- LIVE CRICKET SCORES & NEWS INTERNATIONAL CRICKET COUNCIL. (n.d.). Retrieved from <https://www.icc-cricket.com/>
- LOPES, A. D. D., TIMMONS, M. K. P. A. T. C., GROVER, M. B. S., CICONELLI, R. M. P. M. D. & MICHENER, L. A. P. P. T. A. T. C. 2015. Visual scapular dyskinesis: kinematics and muscle activity alterations in patients with subacromial impingement syndrome. *Archives of Physical Medicine and Rehabilitation*, 96, 298-306.
- MABASA, X. M., STEWART, A. & FLEISHMAN, C. 2002. Isokinetic strength of shoulder internal and external rotators in cricket bowlers. *South African Journal of Physiotherapy*, 58, 35-39.
- MACDONALD, P. B., CLARK, P. & SUTHERLAND, K. 2000. An analysis of the diagnostic accuracy of the Hawkins and Neer subacromial impingement signs. *Journal Of Shoulder and Elbow Surgery*, 9, 299-301.
- MACKENZIE, T. A., HERRINGTON, L., HORLSEY, I. & COOLS, A. 2015. An evidence-based review of current perceptions with regard to the subacromial space in shoulder impingement syndromes: Is it important and what influences it? *Clinical Biomechanics*, 30, 641-648.
- MAKING CRICKET EVEN BETTER. (n.d.). Retrieved from https://www.crichq.com/match_centre/results

- MANSINGH, A. 2011. Posterior ankle impingement in fast bowlers in cricket. *The West Indian Medical Journal*, 60, 77.
- MANSINGH, A., HARPER, L., HEADLEY, S., KING-MOWATT, J. & MANSINGH, G. 2006. Injuries in West Indies cricket 2003-2004. *British Journal of Sports Medicine*, 40, 119-23; discussion 119-23.
- MANSKE, R. & ELLENBECKER, T. 2013. Current concepts in shoulder examination of the overhead athlete. *International Journal of Sports Physical Therapy*, 8, 554.
- MARSH, J. A., WAGSHOL, M. I., BODDY, K. J., O'CONNELL, M. E., BRIEND, S. J., LINDLEY, K. E. & CARAVAN, A. 2018. Effects of a six-week weighted-implement throwing program on baseball pitching velocity, kinematics, arm stress, and arm range of motion. *Peer Journal*, 6, e6003.
- MASCARIN, N. C., DE LIRA, C. A. B., VANCINI, R. L., DE CASTRO POCHINI, A., DA SILVA, A. C. & DOS SANTOS ANDRADE, M. 2017. Strength training using elastic bands: improvement of muscle power and throwing performance in young female handball players. *Journal of Sport Rehabilitation*, 26, 245-252.
- MAZUQUIN, B. F., WRIGHT, A. C., RUSSELL, S., MONGA, P., SELFE, J. & RICHARDS, J. 2018. Effectiveness of early compared with conservative rehabilitation for patients having rotator cuff repair surgery: an overview of systematic reviews. *British Journal of Sports Medicine*, 52, 111-121.
- MCCLURE, P., TATE, A. R., KAREHA, S., IRWIN, D. & ZLUPKO, E. 2009. A clinical method for identifying scapular dyskinesis, part 1: reliability. *Journal of Athletic Training*, 44, 160-164.
- MCFARLAND, E. G., HSU, C.-Y., NEIRA, C. & O'NEIL, O. 1999. Internal impingement of the shoulder: A clinical and arthroscopic analysis. *Journal of Shoulder and Elbow Surgery*, 8, 458-460.
- MCMANARA, D. J., GABBETT, T. J. & NAUGHTON, G. 2017. Assessment of workload and its effects on performance and injury in elite cricket fast bowlers. *Sports Medicine*, 47, 503-515.

- MICHENER, L. A., MCCLURE, P. W. & KARDUNA, A. R. 2003. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clinical Biomechanics* (Bristol, Avon), 18, 369-79.
- MIHATA, T., MCGARRY, M. H., NEO, M., OHUE, M. & LEE, T. Q. 2015. Effect of anterior capsular laxity on horizontal abduction and forceful internal impingement in a cadaveric model of the throwing shoulder. *The American Journal of Sports Medicine*, 43, 1758-1763.
- MONGA, S., PENNA, P. D., CHAPPELL, I., & RASOOL, D. (n.d.). Check Live Cricket Scores, Match Schedules, News, Cricket Videos Online. Retrieved from <https://www.espnccricinfo.com/>
- MORGAN, C. D., BURKHART, S. S., PALMERI, M. & GILLESPIE, M. 1998. Type II SLAP lesions: three subtypes and their relationships to superior instability and rotator cuff tears. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, 14, 553-565.
- MORTON, S., BARTON, C. J., RICE, S. & MORRISSEY, D. 2014. Risk factors and successful interventions for cricket-related low back pain: a systematic review. *British Journal of Sports Medicine*, 48, 685-691.
- MOUNTJOY, M., JUNGE, A., BENJAMEN, S., BOYD, K., DIOP, M., GERRARD, D., VAN DEN HOOGENBAND, C. R., MARKS, S., MARTINEZ-RUIZ, E., MILLER, J., NANOUSIS, K., SHAHPAR, F. M., VELOSO, J., VAN MECHELEN, W. & VERHAGEN, E. A. L. M. 2015. Competing with injuries: injuries prior to and during the 15th FINA World Championships 2013 (aquatics). *British Journal of Sports Medicine*, 49, 37-u73.
- MUIR, S. W., COREA, C. L. & BEAUPRE, L. 2010. Evaluating change in clinical status: reliability and measures of agreement for the assessment of glenohumeral range of motion. *North American Journal of Sports Physical Therapy*, 5, 98-110.
- MULLIGAN, I. J., BIDDINGTON, W. B., BARNHART, B. D. & ELLENBECKER, T. S. 2004. Isokinetic profile of shoulder internal and external rotators of high school aged baseball pitchers. *Journal of Strength and Conditioning Research*, 18, 861-866.
- MURAKAMI, A. M., KOMPTEL, A. J., ENGBRETSSEN, L., LI, X., FORSTER, B. B., CREMA, M. D., HAYASHI, D., JARRAYA, M., ROEMER, F. W. & GUERMAZI,

- A. 2018. The epidemiology of MRI detected shoulder injuries in athletes participating in the Rio de Janeiro 2016 Summer Olympics. *Bio Med Central Musculoskeletal Disorders*, 19, 296-7.
- MURAKI, T. P., YAMAMOTO, N. M. D., ZHAO, K. D. M. A., SPERLING, J. W. M. D. M. B. A., STEINMANN, S. P. M. D., COFIELD, R. H. M. D. & AN, K.-N. P. 2012. Effects of posterior capsule tightness on subacromial contact behavior during shoulder motions. *Journal of Shoulder and Elbow Surgery*, 21, 1160-1167.
- MURRAY, I. R., AHMED, I., WHITE, N. J. & ROBINSON, C. M. 2013. Traumatic anterior shoulder instability in the athlete. *Scandinavian Journal of Medicine & Science in Sports*, 23, 387-405.
- MYERS, J. B., LAUDNER, K. G., PASQUALE, M. R., BRADLEY, J. P. & LEPHART, S. M. 2006a. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *The American Journal of Sports Medicine*, 34, 385-391.
- MYERS, J. B., LAUDNER, K. G., PASQUALE, M. R., BRADLEY, J. P. & LEPHART, S. M. 2006b. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *The American Journal of Sports Medicine*, 34, 385-91.
- MYERS, J. B., OYAMA, S., WASSINGER, C. A., RICCI, R. D., ABT, J. P., CONLEY, K. M. & LEPHART, S. M. 2007. Reliability, precision, accuracy, and validity of posterior shoulder tightness assessment in overhead athletes. *The American Journal of Sports Medicine*, 35, 1922-1930.
- NEALON, A. R. & COOK, J. L. 2018. Trunk Side Strain Has a High Incidence in First-Class Cricket Fast Bowlers in Australia and England. *Clinical Journal of Sports Medicine*, 28, 284-288.
- NEER, C. S., 2ND 1983. Impingement lesions. *Clinical Orthopedics and Related Research*, 70-7.
- NEWMAN, D., FROST, W., ORCHARD, J., STRETCH, R., MANSINGH, A. & LEIPUS, A. 2005. Methods for injury surveillance in international cricket : consensus statement paper. *South African Journal of Sports Medicine*, 17, 18-28.

- NIEDERBRACHT, Y., SHIM, A. L., SLONIGER, M. A., PATERNOSTRO-BAYLES, M. & SHORT, T. H. 2008. Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. *Journal of Strength and Conditioning Research*, 22, 140-145.
- NOFFAL, G. J. 2003. Isokinetic Eccentric-to-Concentric Strength Ratios of the Shoulder Rotator Muscles in Throwers and Nonthrowers. *The American Journal of Sports Medicine*, 31, 537-541.
- OLIVIER, B., STEWART, A. V., GREEN, A. C. & MCKINON, W. 2016a. Cricket pace bowling: The trade-off between optimising knee angle for performance advantages v. injury prevention. *South African Journal of Sports Medicine*, 27, 76.
- OLIVIER, B., TALJAARD, T., BURGER, E., BRUKNER, P., ORCHARD, J., GRAY, J., BOTHA, N., STEWART, A. & MCKINON, W. 2016b. Which extrinsic and intrinsic factors are associated with non-contact injuries in adult cricket fast bowlers? *Sports Medicine*, 46, 79-101.
- ORCHARD, J., JAMES, T., ALCOTT, E., CARTER, S. & FARHART, P. 2002. Injuries in Australian cricket at first class level 1995/1996 to 2000/2001. *British Journal of Sports Medicine*, 36, 270.
- ORCHARD, J. W., BLANCH, P., PAOLONI, J., KOUNTOURIS, A., SIMS, K., ORCHARD, J. J. & BRUKNER, P. 2015. Cricket fast bowling workload patterns as risk factors for tendon, muscle, bone and joint injuries. *British Journal of Sports Medicine*, 49, 1064-1068.
- ORCHARD, J. W., JAMES, T., PORTUS, M., KOUNTOURIS, A. & DENNIS, R. 2009. Fast bowlers in cricket demonstrate up to 3- to 4-week delay between high workloads and increased risk of injury. *American Journal of Sports Medicine*, 37, 1186-92.
- ORCHARD, J. W., JAMES, T. & PORTUS, M. R. 2006. Injuries to elite male cricketers in Australia over a 10-year period. *Journal of Science and Medicine in Sport*, 9, 459-467.

- ORCHARD, J. W., KOUNTOURIS, A. & SIMS, K. 2016a. Incidence and prevalence of elite male cricket injuries using updated consensus definitions. *Open Access Journal of Sports Medicine*, 7, 187-194.
- ORCHARD, J. W., KOUNTOURIS, A. & SIMS, K. 2017. Risk factors for hamstring injuries in Australian male professional cricket players. *Journal of Sport and Health Science*, 6, 271-274.
- ORCHARD, J. W., RANSON, C., OLIVIER, B., DHILLON, M., GRAY, J., LANGLEY, B., MANSINGH, A., MOORE, I. S., MURPHY, I., PATRICIOS, J., ALWAR, T., CLARK, C. J., HARROP, B., KHAN, H. I., KOUNTOURIS, A., MACPHAIL, M., MOUNT, S., MUPOTARINGA, A., NEWMAN, D., O'REILLY, K., PEIRCE, N., SALEEM, S., SHACKEL, D., STRETCH, R. & FINCH, C. F. 2016b. International consensus statement on injury surveillance in cricket: a 2016 update. *British Journal of Sports Medicine*, 50, 1245-1251.
- PAGE, P. 2011. Shoulder muscle imbalance and subacromial impingement syndrome in overhead athletes. *International Journal of Sports Physical Therapy*, Journal Article, 6, 51.
- PARDIWALA, D. N., RAO, N. N. & VARSHNEY, A. V. 2018. Injuries in cricket. *Sports Health: A Multidisciplinary Approach*, 10, 217-222.
- PARK, J.-Y. 2015. Sports Injuries to the Shoulder And Elbow, New York;Berlin;, Springer.
- PERERA, N., KOUNTOURIS, A., KEMP, J., JOSEPH, C. & FINCH, C. 2017. Injuries in elite australian female cricketers. *British Journal of Sports Medicine*, 51, 373-373.
- POPP, D. & SCHÖFFL, V. 2015. Superior labral anterior posterior lesions of the shoulder: Current diagnostic and therapeutic standards. *World Journal of Orthopedics*, 6, 660.
- PRABHAKAR, S. & PANDEY, R. 2015. Shoulder injuries in cricketers. *Journal of Postgraduate Medicine Education and Research*, 49, 194-196.
- PRIBBLE, J. M., TROWBRIDGE, M. J., KAMAT, S. V., FOWLER, E. F., GOLDSTEIN, K. M., & HARGARTEN, S. W. (2008). Injury reporting on local TV news: a prime-time opportunity for prevention. *American Journal of Preventive Medicine*, 34(5), 420-423

- RANSON, C. & GREGORY, P. L. 2007. Shoulder injury in professional cricketers. *Physical Therapy in Sport*, 9, 34-39.
- RANSON, C., HURLEY, R., RUGLESS, L., MANSINGH, A. & COLE, J. 2013. International cricket injury surveillance: a report of five teams competing in the ICC Cricket World Cup 2011. *British Journal of Sports Medicine*, 47, 637-643.
- RISTOLAINEN, L., HEINONEN, A., TURUNEN, H., MANNSTROM, H., WALLER, B., KETTUNEN, J. A. & KUJALA, U. M. 2010. Type of sport is related to injury profile: a study on cross country skiers, swimmers, long-distance runners and soccer players. A retrospective 12-month study. *Scandinavian Journal of Medicine & Science in Sports*, 20, 384-93.
- ROACH, K. E., BUDIMAN-MAK, E., SONGSIRIDEJ, N. & LERTRATANAKUL, Y. 1991. Development of a shoulder pain and disability index. *Arthritis & Rheumatism: Official Journal of the American College of Rheumatology*, 4, 143-149.
- ROBSON, B., PURDIE, G., CRAM, F. & SIMMONDS, S. 2007. Age standardisation - an indigenous standard? *Emerging Themes in Epidemiology*, 4, 3.
- ROCA, M., ELLIOTT, B., ALDERSON, J. & FOSTER, D. 2006. The relationship between shoulder alignment and elbow joint angle in cricket fast-medium bowlers. *Journal of Sports Sciences*, 24, 1127-1135.
- ROSA, D. P., CAMARGO, P. R. & BORSTAD, J. D. 2018. The influence of posterior glenohumeral joint capsule tightness and humeral retroversion on clinical measurements. *Physical Therapy in Sport*, 34, 148-153.
- SABARI, J. S., MALTZEV, I., LUBARSKY, D., LISZKAY, E. & HOMEL, P. 1998. Goniometric assessment of shoulder range of motion: comparison of testing in supine and sitting positions. *Archives of Physical Medicine and Rehabilitation*, 79, 647-651.
- SACHLIKIDIS, A. & SALTER, C. 2007. A biomechanical comparison of dominant and non-dominant arm throws for speed and accuracy. *Sports Biomechanics*, 6, 334-344.
- SANO, H., HATTA, T., YAMAMOTO, N. & ITOI, E. 2013. Stress distribution within rotator cuff tendons with a crescent-shaped and an L-shaped tear. *The American Journal of Sports Medicine*, 41, 2262-2269.

- SAW, R., DENNIS, R. J., BENTLEY, D. & FARHART, P. 2011. Throwing workload and injury risk in elite cricketers. *British Journal of Sports Medicine*, 45, 805-808.
- SCHER, S., ANDERSON, K., WEBER, N., BAJOREK, J., RAND, K. & BEY, M. J. 2010. Associations among hip and shoulder range of motion and shoulder injury in professional baseball players. *Journal of Athletic Training*, 45, 191-197.
- SEGI, M. 1969. Cancer mortality for selected sites in 24 countries, Japan Cancer Society.
- SEIN, M. L., WALTON, J., LINKLATER, J., APPELYARD, R., KIRKBRIDE, B., KUAH, D. & MURRELL, G. A. C. 2010. Shoulder pain in elite swimmers: primarily due to swim-volume-induced supraspinatus tendinopathy. *British Journal of Sports Medicine*, 44, 105-113.
- SEITZ, A. L., MCCLURE, P. W., FINUCANE, S., BOARDMAN III, N. D. & MICHENER, L. A. 2011. Mechanisms of rotator cuff tendinopathy: intrinsic, extrinsic, or both? *Clinical Biomechanics*, 26, 1-12.
- SEROYER, S. T., NHO, S. J., BACH, B. R., JR., BUSH-JOSEPH, C. A., NICHOLSON, G. P. & ROMEO, A. A. 2009. Shoulder pain in the overhead throwing athlete. *Sports Health*, 1, 108-120.
- SGROI, T. A. & ZAJAC, J. M. 2018. Return to throwing after shoulder or elbow injury. *Current Reviews in Musculoskeletal Medicine*, 11, 12-18.
- SHANLEY, E. & THIGPEN, C. 2013. Throwing injuries in the adolescent athlete. *International Journal of Sports Physical Therapy*, 8, 630-640.
- SHARMA, M., JEBA, C. & KHATRI, S. 2012. Double Crossed Syndrome in Cricketer's Shoulder: RCT. *Journal of Exercise Science and Physiotherapy*, 8, 119.
- SHIM, A. & NIEDERBRACHT, Y. 2014. Can a 5 week strength training program produce range of motion adaptations in amateur female tennis players? *Journal of Science and Medicine in Sport*, 18, e86-e86.
- SHIRE, A. R., STÆHR, T. A. B., OVERBY, J. B., BASTHOLM DAHL, M., SANDELL JACOBSEN, J. & HØYRUP CHRISTIANSEN, D. 2017. Specific or general exercise strategy for subacromial impingement syndrome—does it matter? A systematic

- literature review and meta analysis. *British Medical Council Musculoskeletal Disorders*, 18, 158.
- SILVA, P. V., KAMPER, S. J. & DA CUNHA MENEZES COSTA, L. 2018. Exercise-based intervention for prevention of sports injuries (PEDro synthesis). *British Journal of Sports Medicine*, 52, 408.
- SMUCNY, M., KOLMODIN, J. & SALUAN, P. 2016. Shoulder and Elbow Injuries in the Adolescent Athlete. *Sports Medicine And Arthroscopy Review*, Journal Article, 24, 188.
- SOLIGARD, T., STEFFEN, K., PALMER-GREEN, D., AUBRY, M., GRANT, M.-E., MEEUWISSE, W., MOUNTJOY, M., BUDGETT, R. & ENGBRETSSEN, L. 2015. Sports injuries and illnesses in the Sochi 2014 Olympic Winter Games. *British Journal of Sports Medicine*, 49, 441-447.
- SONNON, S. 2006. The Big Book of Clubbelt Training, RMAX. tv Productions.
- SOOMRO, N., STRASIOTTO, L., SAWDAGAR, T., LYLE, D., MILLS, D., FERDINANDS, R. & SANDERS, R. 2018. Cricket injury epidemiology in the twenty-first century: what is the burden? *Sports Medicine*, 48, 2301-2316.
- SPRATFORD, W. & HICKS, A. 2014. Increased delivery stride length places greater loads on the ankle joint in elite male cricket fast bowlers. *Journal of Sports Sciences*, 32, 1101-1109.
- STANDARD POPULATIONS (MILLIONS) FOR AGE-ADJUSTMENT - SEER Population Datasets. (n.d.). Retrieved from <https://seer.cancer.gov/stdpopulations/>
- STEURI, R., SATTELMAYER, M., ELSIG, S., KOLLY, C., TAL, A., TAEYMANS, J. & HILFIKER, R. 2017. Effectiveness of conservative interventions including exercise, manual therapy and medical management in adults with shoulder impingement: a systematic review and meta-analysis of RCTs. *British Journal of Sports Medicine*, 51, 1340-1347.
- STONEHAM, M., BOSS, A., & DAUBE, M. (2013). Monitoring injury reporting in selected Australian media: a potential advocacy strategy? *Health Promotion Journal of Australia*, 24(1), 61–64. doi: 10.1071/he12911

- STRETCH, R. A. 2003. Cricket injuries: a longitudinal study of the nature of injuries to South African cricketers. *British Journal of Sports Medicine*, 37, 250-253.
- STUELCKEN, M. C., GINN, K. A. & SINCLAIR, P. J. 2007. Shoulder strength and range of motion in elite female cricket fast bowlers with and without a history of shoulder pain. *Journal of Science and Medicine in Sport*, 11, 575-580.
- SUNDARAM, B., BHARGAVA, S. & KARUPPANNAN, S. 2012a. Glenohumeral rotational range of motion differences between fast bowlers and spin bowlers in elite cricketers. *International Journal of Sports Physical Therapy*, 7, 576.
- SUNDARAM, B., SKN, B. & KARUPPANNAN, S. 2012b. Glenohumeral rotational range of motion differences between fast bowlers and spin bowlers in elite cricketers. *International Journal of Sports Physical Therapy*, 7, 576.
- TANIGUCHI, N., D'LIMA, D. D., SUENAGA, N., ISHIDA, Y., LEE, D., GOYA, I. & CHOSA, E. 2017. Translation of the humeral head scale is associated with success of rotator cuff repair for large-massive tears. *Bio Med Central Musculoskeletal Disorders*, 18, 511-8.
- TANNENBAUM, E. & SEKIYA, J. K. 2011. Evaluation and management of posterior shoulder instability. *Sports Health*, 3, 253-263.
- TEYHEN, D. S., MILLER, J. M., MIDDAG, T. R. & KANE, E. J. 2008. Rotator cuff fatigue and glenohumeral kinematics in participants without shoulder dysfunction. *Journal of Athletic Training*, 43, 352-358.
- THE THREE FORMATS OF CRICKET. (2017, January 29). Retrieved from <https://www.icc-cricket.com/about/cricket/game-formats/the-three-formats>
- THOMAS, S. J., SWANIK, K. A., SWANIK, C. B. & KELLY, J. D. 2010. Internal rotation and scapular position differences: a comparison of collegiate and high school baseball players. *Journal of Athletic Training*, 45, 44-50.
- TIMMONS, M. K., THIGPEN, C. A., SEITZ, A. L., KARDUNA, A. R., ARNOLD, B. L. & MICHENER, L. A. 2012a. Scapular kinematics and subacromial-impingement syndrome: a meta-analysis. *Journal Sport Rehabilitation*, 21, 354-70.

- TIMMONS, M. K., THIGPEN, C. A., SEITZ, A. L., KARDUNA, A. R., ARNOLD, B. L. & MICHENER, L. A. 2012b. Scapular kinematics and subacromial-impingement syndrome: a meta-analysis. *Journal of Sport Rehabilitation*, 21, 354-370.
- UHL, T. L., KIBLER, W. B., GECEWICH, B. & TRIPP, B. L. 2009. Evaluation of clinical assessment methods for scapular dyskinesis. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, 25, 1240-1248.
- VAN BEIJSTERVELDT, A. M. C., VAN DER HORST, N., VAN DE PORT, I. G. L. & BACKX, F. J. G. 2013. How effective are exercise-based injury prevention programmes for soccer players? a systematic review. *Sports Medicine*, 43, 257-265.
- VAN DER WINDT, D. A., KOES, B. W., DE JONG, B. A. & BOUTER, L. M. 1995. Shoulder disorders in general practice: incidence, patient characteristics, and management. *American Rheumatoid Disease*, 54, 959-64.
- VAN MECHELEN, W., HLOBIL, H. & KEMPER, H. C. 1992. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Medicine* (Auckland, N.Z.), 14, 82.
- VODIČKA, T., ZVONAR, M., PAČES, J., KNJAZ, D., RUŽBARSKÝ, P. & ŽHÁNĚL, J. 2018. Strength values of shoulder internal and external rotators in junior tennis players. *Kinesiology*, 50, 181-187.
- WALDMAN, S. D. M. D. J. D. 2016. An overview of shoulder impingement syndromes. Third ed.
- WANG, H. & COCHRANE, T. 2001. Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. *Journal of Sports Medicine and Physical Fitness*, 41, 403-410.
- WANG, H. K., MACFARLANE, A. & COCHRANE, T. 2000. Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *British Journal of Sports Medicine*, 34, 39-43.
- WATERHOUSE, J. 1982. "Cancer incidence in five continents, Vol. IV,". *IARC Scientific Publications*.

- WATSON, S., ALLEN, B. & GRANT, J. A. 2016. A clinical review of return-to-play considerations after anterior shoulder dislocation. *Sports Health*, 8, 336-341.
- WATTS, A. R., WILLIAMS, B., KIM, S. W., BRAMWELL, D. C. & KRISHNAN, J. 2017. Shoulder impingement syndrome: a systematic review of clinical trial participant selection criteria. *Shoulder & Elbow*, 9, 31-41.
- WEISS, L. J., WANG, D., HENDEL, M., BUZZERIO, P. & RODEO, S. A. 2018. Management of rotator cuff injuries in the elite athlete. *Current Reviews in Musculoskeletal Medicine*, 11, 102-112.
- WHITELEY, R. & OCEGUERA, M. 2016. GIRD, TRROM, and humeral torsion-based classification of shoulder risk in throwing athletes are not in agreement and should not be used interchangeably. *Journal of Science and Medicine in Sport*, 19, 816-819.
- WILK, K. E., MACRINA, L. C., CAIN, E. L., DUGAS, J. R. & ANDREWS, J. R. 2013. The recognition and treatment of superior labral (slap) lesions in the overhead athlete. *International Journal of Sports Physical Therapy*, 8, 579-600.
- WILK, K. E., MACRINA, L. C., FLEISIG, G. S., AUNE, K. T., PORTERFIELD, R. A., HARKER, P., EVANS, T. J. & ANDREWS, J. R. 2015. Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers: a prospective study. *The American Journal of Sports Medicine*, 43, 2379-2385.
- WOLF, B. R., EBINGER, A. E., LAWLER, M. P. & BRITTON, C. L. 2009. Injury patterns in division I collegiate swimming. *The American Journal of Sports Medicine*, 37, 2037-2042.
- WORTHINGTON, P. J. 2010. A biomechanical analysis of fast bowling in cricket. *Dissertation/Thesis*, Loughborough University.
- WYMORE, L. & FRONEK, J. 2015. Shoulder functional performance status of national collegiate athletic association swimmers: baseline Kerlan-Jobe orthopedic clinic scores. *The American Journal of Sports Medicine*, 43, 1513-1517.

YU, I., KIM, T., JUNG, D. & OH, J. 2016. Effects of posterior shoulder stretches on the isokinetic strength of rotator cuff muscles in youth baseball players with scapular dyskinesis. *Manual Therapy*, 25, e128-e129.

Appendix A- Study 3

- 1. Ethics approval**
- 2. Consent forms**
- 3. Information sheet for participants**
- 4. Cricket injury survey**

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2016/74/LR-PS

20 December 2016

Sibi Boycott Noel Walter
School of Health Sciences
UNIVERSITY OF CANTERBURY

Dear Sibi

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Shoulder Injuries Among Cricket Pace Bowlers, Competitive Swimmers and Baseball Pitchers".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your emails of 30th November and 13th December.

With best wishes for your project.

Yours sincerely

R. Robinson

pp.

Associate Professor Jane Maidment
Chair, Human Ethics Committee

Consent Form from Sporting Authority

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz
30/11/16



Injuries among Cricket Pace Bowlers

(Please tick the following)

- ☒ We have been given a full explanation of this project and have had the opportunity to ask questions.
- ☒ We understand what is required of the athletes if they agree to take part in the research.
- ☒ We understand that athlete participation is voluntary and they may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information the athletes have provided should this remain practically achievable.
- ☒ We understand that any information or opinions that the athletes provide will be kept confidential to the researcher *Mr. Sibi Walter and Dr. Carl Petersen* and that any published or reported results will not identify the participants. We understand that a thesis is a public document and will be available through the UC Library.
- ☒ We understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after *ten* years.
- ☒ We understand the risks associated with the athletes taking part in the study and how they will be managed.
- ☒ We understand that we will be able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.
- ☒ We understand that we can contact the researcher *Sibi Walter* (sibi.walter@pg.canterbury.ac.nz) or supervisor *Dr. Carl Petersen* (carl.petersen@canterbury.ac.nz) for further information. If we have any complaints, we can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☒ We would like a summary of the results of the project.
- ☒ By signing below, we agree to give permission to Mr. Sibi Walter to conduct this research and to contact our association athletes to participate in this research project.

Name: Brandon Donkers Signed: *Brandon Donkers* Date: 5.7.2017

Email address: *bdonkers@canterburycricket.org.nz*

Please return the form to the researcher or send it via email to sibi.walter@pg.canterbury.ac.nz or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

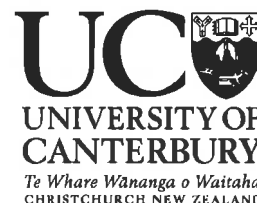
Consent Form from Sporting Authority

Department: School of Sport and Physical Education

Telephone: +64 33642506

Email: sibi.walter@pg.canterbury.ac.nz

30/11/16



Injuries among Cricket Pace Bowlers

(Please tick the following)

- ☒ We have been given a full explanation of this project and have had the opportunity to ask questions.
- ☒ We understand what is required of the athletes if they agree to take part in the research.
- ☒ We understand that athlete participation is voluntary and they may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information the athletes have provided should this remain practically achievable.
- ☒ We understand that any information or opinions that the athletes provide will be kept confidential to the researcher *Mr. Sibi Walter and Dr. Carl Petersen* and that any published or reported results will not identify the participants. We understand that a thesis is a public document and will be available through the UC Library.
- ☒ We understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after *ten* years.
- ☒ We understand the risks associated with the athletes taking part in the study and how they will be managed.
- ☒ We understand that we will be able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.
- ☒ We understand that we can contact the researcher *Sibi Walter* (sibi.walter@pg.canterbury.ac.nz) or supervisor *Dr. Carl Petersen* (carl.petersen@canterbury.ac.nz) for further information. If we have any complaints, we can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☒ We would like a summary of the results of the project.
- ☒ By signing below, we agree to give permission to Mr. Sibi Walter to conduct this research and to contact our association athletes to participate in this research project.

Name: Lance Hamilton Signed:  Date: 9/11/17
Email address: lance@cdcricket.co.nz.

Please return the form to the researcher or send it via email to sibi.walter@pg.canterbury.ac.nz or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

Consent Form from Sporting Authority

Department: School of Sport and Physical Education

Telephone: +64 33642506

Email: sibi.walter@pg.canterbury.ac.nz

30/11/16



Injuries among Cricket Pace Bowlers

(Please tick the following)

- ☒ We have been given a full explanation of this project and have had the opportunity to ask questions.
- ☒ We understand what is required of the athletes if they agree to take part in the research.
- ☒ We understand that athlete participation is voluntary and they may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information the athletes have provided should this remain practically achievable.
- ☒ We understand that any information or opinions that the athletes provide will be kept confidential to the researcher *Mr. Sibi Walter and Dr. Carl Petersen* and that any published or reported results will not identify the participants. We understand that a thesis is a public document and will be available through the UC Library.
- ☒ We understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after *ten* years.
- ☒ We understand the risks associated with the athletes taking part in the study and how they will be managed.
- ☒ We understand that we will be able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.
- ☒ We understand that we can contact the researcher *Sibi Walter* (sibi.walter@pg.canterbury.ac.nz) or supervisor *Dr. Carl Petersen* (carl.petersen@canterbury.ac.nz) for further information. If we have any complaints, we can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☒ We would like a summary of the results of the project.
- ☒ By signing below, we agree to give permission to Mr. Sibi Walter to conduct this research and to contact our association athletes to participate in this research project.

Name: *Glenn Beckwith* Signed: *[Signature]* Date: *12/9/17*

Email address: *g.beckwith@hobbs.co.nz*

Please return the form to the researcher or send it via email to sibi.walter@pg.canterbury.ac.nz or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

Consent Form from Sporting Authority

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz
30/11/16



Injuries among Cricket Pace Bowlers

(Please tick the following)

- ☒ We have been given a full explanation of this project and have had the opportunity to ask questions.
- ☒ We understand what is required of the athletes if they agree to take part in the research.
- ☒ We understand that athlete participation is voluntary and they may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information the athletes have provided should this remain practically achievable.
- ☒ We understand that any information or opinions that the athletes provide will be kept confidential to the researcher *Mr. Sibi Walter and Dr. Carl Petersen* and that any published or reported results will not identify the participants. We understand that a thesis is a public document and will be available through the UC Library.
- ☒ We understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after *ten* years.
- ☒ We understand the risks associated with the athletes taking part in the study and how they will be managed.
- ☒ We understand that we will be able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.
- ☒ We understand that we can contact the researcher *Sibi Walter* (sibi.walter@pg.canterbury.ac.nz) or supervisor *Dr. Carl Petersen* (carl.petersen@canterbury.ac.nz) for further information. If we have any complaints, we can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☒ We would like a summary of the results of the project.
- ☒ By signing below, we agree to give permission to Mr. Sibi Walter to conduct this research and to contact our association athletes to participate in this research project.

Name: Simon Forde Signed: [Signature] Date: 13/9/17
Email address: simon@ofegocricket.co.nz

Please return the form to the researcher or send it via email to sibi.walter@pg.canterbury.ac.nz or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

Information Sheet for Sporting Authority

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz
30/11/16



Injuries among Cricket Pace Bowlers

My name is Sibi Walter and I'm a sports physiotherapist doing PhD research study at the University of Canterbury. I would like to conduct a research study among the pace bowlers in your organization, to find out the number of injuries that occur to Cricket pace bowlers in a 12 month period.

Explanation: A pace bowler choosing to partake in this study will be required to answer a questionnaire which takes about 10 minutes to complete. They will be provided with the information sheet, consent form and the questionnaire. The questionnaire will ask about the injuries they have had in the past 12 months. They can either fill out a hard paper copy or online survey.

Please note, participation is voluntary and the bowlers have the right to withdraw at any stage without penalty and they may ask for their raw data to be deleted. If they withdraw, information relating to them will be deleted.

For convenience the survey is designed to allow the pace bowler to complete it using their smart phones, tablets or computers. With New Zealand Cricket's approval I will require a list of the email addresses of the pace bowlers so that I could send a web link of the survey to them.

I'm aiming at publishing the results of the questionnaire however this will be average data and all bowler's information will be anonymous. To ensure anonymity and confidentiality, Participant identity will be made confidential a coded number will be allotted to each athlete on the consent form and only the researchers will have access to the codes. All the consent forms, bowler filled out questionnaire, injury data will be kept in a private password protected computer and the university server will be used to back it up. Data will be coded for maintaining confidentiality and it would be destroyed after 10 years as the HEC principle for a PhD research. The surveys received as hard copy will be stored in a locked filing cabinet only the researcher will be having access to them. The injury data results will be published as part of the PhD thesis and I will target publishing the data as a journal article in a sports medicine journal. A thesis is a public document and will be available through the UC Library.

Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project.

The project is being carried out *as a requirement for a PhD degree* by Mr. Sibi Walter under the supervision of Dr. Carl Petersen, who can be contacted at carl.petersen@canterbury.ac.nz. They will be pleased to discuss any concerns you may have about the project.

Consent Form from Sporting Authority

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz
30/11/16



Injuries among Cricket Pace Bowlers

(Please tick the following)

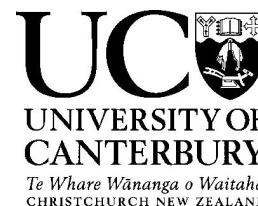
- ☒ We have been given a full explanation of this project and have had the opportunity to ask questions.
- ☒ We understand what is required of the athletes if they agree to take part in the research.
- ☒ We understand that athlete participation is voluntary and they may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information the athletes have provided should this remain practically achievable.
- ☒ We understand that any information or opinions that the athletes provide will be kept confidential to the researcher *Mr. Sibi Walter and Dr. Carl Petersen* and that any published or reported results will not identify the participants. We understand that a thesis is a public document and will be available through the UC Library.
- ☒ We understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after *ten* years.
- ☒ We understand the risks associated with the athletes taking part in the study and how they will be managed.
- ☒ We understand that we will be able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.
- ☒ We understand that we can contact the researcher
Sibi Walter (sibi.walter@pg.canterbury.ac.nz) or supervisor Dr. Carl Petersen (carl.petersen@canterbury.ac.nz) for further information. If we have any complaints, we can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☒ We would like a summary of the results of the project.
- ☒ By signing below, we agree to give permission to Mr. Sibi Walter to conduct this research and to contact our association athletes to participate in this research project.

Name: Peter Zanzottera Signed: P. Zanzottera Date: 22/9/17
Email address: peterz@ndca.co.nz

Please return the form to the researcher or send it via email to sibi.walter@pg.canterbury.ac.nz or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

Information Sheet for Sporting Authority

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz
30/11/16



Injuries among Cricket Pace Bowlers

My name is Sibi Walter and I'm a sports physiotherapist doing PhD research study at the University of Canterbury. I would like to conduct a research study among the pace bowlers in your organization, to find out the number of injuries that occur to Cricket pace bowlers in a 12 month period.

Explanation: A pace bowler choosing to partake in this study will be required to answer a questionnaire which takes about 10 minutes to complete. They will be provided with the information sheet, consent form and the questionnaire. The questionnaire will ask about the injuries they have had in the past 12 months. They can either fill out a hard paper copy or online survey.

Please note, participation is voluntary and the bowlers have the right to withdraw at any stage without penalty and they may ask for their raw data to be deleted. If they withdraw, information relating to them will be deleted.

For convenience the survey is designed to allow the pace bowler to complete it using their smart phones, tablets or computers. With New Zealand Cricket's approval I will require a list of the email addresses of the pace bowlers so that I could send a web link of the survey to them.

I'm aiming at publishing the results of the questionnaire however this will be average data and all bowler's information will be anonymous. To ensure anonymity and confidentiality, Participant identity will be made confidential a coded number will be allotted to each athlete on the consent form and only the researchers will have access to the codes. All the consent forms, bowler filled out questionnaire, injury data will be kept in a private password protected computer and the university server will be used to back it up. Data will be coded for maintaining confidentiality and it would be destroyed after 10 years as the HEC principle for a PhD research. The surveys received as hard copy will be stored in a locked filing cabinet only the researcher will be having access to them. The injury data results will be published as part of the PhD thesis and I will target publishing the data as a journal article in a sports medicine journal. A thesis is a public document and will be available through the UC Library.

Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project.

The project is being carried out *as a requirement for a PhD degree* by Mr. Sibi Walter under the supervision of Dr. Carl Petersen, who can be contacted at carl.petersen@canterbury.ac.nz. They will be pleased to discuss any concerns you may have about the project.

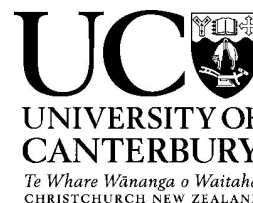
This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to permit this study and have no objection, you are asked to complete the consent form and return it to the researcher or send it via email to *sibi.walter@pg.canterbury.ac.nz* or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041*.

*Thanks and Regards,
Sibi Walter.*

Consent Form from Sporting Authority

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz
30/11/16



Injuries among Cricket Pace Bowlers

(Please tick the following)

- ☐ We have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ We understand what is required of the athletes if they agree to take part in the research.
- ☐ We understand that athlete participation is voluntary and they may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information the athletes have provided should this remain practically achievable.
- ☐ We understand that any information or opinions that the athletes provide will be kept confidential to the researcher *Mr. Sibi Walter and Dr. Carl Petersen* and that any published or reported results will not identify the participants. We understand that a thesis is a public document and will be available through the UC Library.
- ☐ We understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after *ten* years.
- ☐ We understand the risks associated with the athletes taking part in the study and how they will be managed.
- ☐ We understand that we will be able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.
- ☐ We understand that we can contact the researcher
Sibi Walter (sibi.walter@pg.canterbury.ac.nz) or supervisor *Dr. Carl Petersen* (carl.petersen@canterbury.ac.nz) for further information. If we have any complaints, we can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ We would like a summary of the results of the project.
- ☐ By signing below, we agree to give permission to Mr. Sibi Walter to conduct this research and to contact our association athletes to participate in this research project.

Name: Simon Insley Signed: _____

Date: 15/9/17

Email address: sinsley@aucklandcricket.co.nz

Please return the form to the researcher or send it via email to sibi.walter@pg.canterbury.ac.nz or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

Information Sheet for Participants

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz
30/11/16



Injuries among Cricket Pace Bowlers

You are invited to participate in a research study investigating injuries among New Zealand Cricket Pace bowlers. Your participation in this study requires 10 minutes of your time to answer a survey on sports injuries you have had in the past 12 months.

Researcher info: *My name is Sibi Walter; I'm a sports physiotherapist and a PhD student, studying at the University of Canterbury. This study is endorsed by New Zealand Cricket.*

Study purpose: *To determine the prevalence of injuries occurring to Pace bowlers within a 12 month period and explore the injury mechanism. The study will determine which body part has the highest incidence.*

Explanation: If you choose to participate you will answer a 10 minute questionnaire. After reading this information sheet you can sign the consent form attached to it and then answer the questionnaire. The questionnaire contains questions on the sports injuries that you have had in the past 12 months. You can choose to answer a paper questionnaire or an online survey which will be provided by email address.

Participation is voluntary and you have the right to withdraw at any stage. If you withdraw, all your information will be deleted.

I'm aiming at publishing the results of the questionnaire however it will be only average data and all bowler's identity will be anonymous. To ensure anonymity and confidentiality, Participant identity will be made confidential a coded number will be allotted to each bowler on the consent form and only the researchers will have access to the codes. All the consent forms, bowler filled out questionnaire, injury data will be kept in a private password protected computer and the university server will be used to back it up. Data will be coded for maintaining confidentiality and it will be destroyed after 10 years as the HEC principle for a PhD research. The surveys received as hard copy will be stored in a locked filing cabinet only the researcher will be having access to them. The injury data results will be published as part of the PhD thesis and I will target publishing the data as a journal article in a sports medicine journal. A thesis is a public document and will be available through the UC Library.

Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project.

The project is being carried out *as a requirement for a PhD degree* by Mr. Sibi Walter under the supervision of Dr. Carl Petersen, who can be contacted at carl.petersen@canterbury.ac.nz. They will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return it to the researcher or send it via email to *sibi.walter@pg.canterbury.ac.nz* or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041*.

*Thanks and Regards,
Sibi Walter.*

Consent Form for Participants

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz
30/11/16



Injuries among Cricket Pace Bowlers *(Please tick the following)*

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher *Mr. Sibi Walter and Dr. Carl Petersen* and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after *ten* years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.
- ☐ I understand that I can contact the researcher *Sibi Walter* (sibi.walter@pg.canterbury.ac.nz) or supervisor *Dr. Carl Petersen* (carl.petersen@canterbury.ac.nz) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ I would like a summary of the results of the project.
- ☐ By signing below, I agree to participate in this research project.

Name: _____ Signed: _____ Date: _____

Email address: _____

Please return the form to the researcher or send it via email to sibi.walter@pg.canterbury.ac.nz or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

Thanks and Regards,
Sibi Walter.

CRICKET BOWLERS INJURY SURVEY

Cricket Bowlers Injury Survey

SECTION A - PLAYER INFORMATION : Please answer all questions

Please provide your player information

Date of Birth

Gender

Height in Centimeters

Weight in Kilograms

How do you categorize your bowling speed?

Fast

☐

Medium

☐

Slow

☐

What is your dominant bowling arm?

Right

☐

Left

☐

What is your bowling action?

Front on

☐

Side on

☐

Mixed

☐

SECTION B - TRAINING INFORMATION: This section is only about your training hours and resting days in the past season. If you do not have an answer please put the number "0". Please answer all the questions using only NUMBERS

How many weeks did you train for Cricket, before the playing season started?

weeks

During your last pre-season, on average how many HOURS IN A WEEK did you train for Cricket?

pre season hours per week

During your last playing season, on average how many HOURS IN A WEEK did you train for Cricket?

playing season hours per week

How many total weeks over the past 12 months did you actually play Cricket?

weeks

How many Multi day matches have you participated in the last 12 months?

multi day

estimated total days

How many One day matches have you participated in the last 12 months?

one day

How many Twenty twenty (T20) matches have you participated in the last 12 months?

T20

Have you attended any training camps in the past 12 months?

Yes

☐

No

☐

What is the total number of days you were involved in training camps in the past 12 months?

total number of days

During the Pre-season on average how many NON BOWLING DAYS PER WEEK did you have?

pre-season non bowling days/week

During the Playing season on an average how many NON BOWLING DAYS PER WEEK did you have?

playing season non bowling days/week

SECTION C-ACUTE INJURY REPORT: An acute injury is any injury which occurred suddenly or accidentally. It may or may not have interrupted your training session or your match. An acute injury is also any physical injury that has kept you away from at least a single training session or match. It may or may not have needed a physiotherapist or doctor's care.

Have you had any acute injuries related to Cricket in the last 12 months?

Yes

☐

No

☐

In which body part did you have this acute injury?

☐ Shoulder

☐ Elbow

☐ Forearm

☐ Wrist & Hand

☐ Hip

☐ Thigh

☐ Knee

☐ Calf

☐ Shin

☐ Ankle & Foot

☐ Head & Face

☐ Neck

☐ Chest

☐ Upper back

☐ Lower back

☐ Abdominals

☐ Side of the Trunk

☐ Groin

Which side of your body did this acute injury occur?

Right

☐

Left

☐

Middle

☐

How would you describe this acute injury?

- ☐ Muscle Cramp
- ☐ Muscle Strain
- ☐ Wound/Bruise
- ☐ Ligament strain/rupture
- ☐ Dislocation
- ☐ Fracture
- ☐ Muscle soreness
- ☐ Unidentified pain

What activity were you doing at the time of this acute injury?

- ☐ Bowling
- ☐ Batting
- ☐ Fielding
- ☐ Wicket Keeping
- ☐ Other activity

Which situation did you have this acute injury onset?

- ☐ During a match
- ☐ Pre match warm-up
- ☐ After match cool down
- ☐ Team training session
- ☐ Supervised individual training
- ☐ Training alone

How did the doctor or physio term this acute injury? If known, write the medical diagnosis of this acute injury?

medical diagnosis

How many DAYS did you miss due to this acute injury? (If none put the number "0")

In season (playing season)

Off season (pre-season)

Did this acute injury reoccur? ("i.e" same body part and same side)

Yes

☐

No

☐

How would you describe this recurrent acute injury?

- ☐ Muscle Cramp
- ☐ Muscle Strain
- ☐ Wound/Bruise
- ☐ Ligament strain/rupture
- ☐ Dislocation
- ☐ Fracture
- ☐ Muscle soreness
- ☐ Unidentified pain

Did you have another other acute injury in the past 12 months?

Yes

☐

No

☐

In which body part did you have this acute injury?

- | | |
|------------------------------------|---|
| <input type="radio"/> Shoulder | <input type="radio"/> Ankle & Foot |
| <input type="radio"/> Elbow | <input type="radio"/> Head & Face |
| <input type="radio"/> Forearm | <input type="radio"/> Neck |
| <input type="radio"/> Wrist & Hand | <input type="radio"/> Chest |
| <input type="radio"/> Hip | <input type="radio"/> Upper back |
| <input type="radio"/> Thigh | <input type="radio"/> Lower back |
| <input type="radio"/> Knee | <input type="radio"/> Abdominals |
| <input type="radio"/> Calf | <input type="radio"/> Side of the Trunk |
| <input type="radio"/> Shin | <input type="radio"/> Groin |

Which side of your body did this acute injury occur?

Right

☐

Left

☐

Middle

☐

How would you describe this acute injury?

- ☐ Muscle Cramp
- ☐ Muscle Strain
- ☐ Wound/Bruise
- ☐ Ligament strain/rupture
- ☐ Dislocation
- ☐ Fracture
- ☐ Muscle soreness
- ☐ Unidentified pain

What activity were you doing at the time of this acute injury?

- ☐ Bowling
- ☐ Batting
- ☐ Fielding
- ☐ Wicket Keeping
- ☐ Other activity

Which situation did you have this acute injury onset?

- ☐ During a match
- ☐ Pre match warm up
- ☐ After match cool down
- ☐ Team training session
- ☐ Supervised individual training
- ☐ Training alone

How did the doctor or physio term this acute injury? If known, write the medical diagnosis of this acute injury?

medical diagnosis

How many number of days did you miss due to this acute injury? (If none put the number "0")

In season (playing season)

Off season (pre-season)

Did this acute injury reoccur? ("i.e" same body part and same side)

Yes

☐

No

☐

How would you describe this recurrent acute injury?

- ☐ Muscle Cramp
- ☐ Muscle Strain
- ☐ Wound/Bruise
- ☐ Ligament strain/rupture
- ☐ Dislocation
- ☐ Fracture
- ☐ Muscle soreness
- ☐ Unidentified pain

Did you have another acute injury in the past 12 months?

Yes

☐

No

☐

In which body part did you have this acute injury?

- | | |
|------------------------------------|---|
| <input type="radio"/> Shoulder | <input type="radio"/> Ankle & Foot |
| <input type="radio"/> Elbow | <input type="radio"/> Head & Face |
| <input type="radio"/> Forearm | <input type="radio"/> Neck |
| <input type="radio"/> Wrist & Hand | <input type="radio"/> Chest |
| <input type="radio"/> Hip | <input type="radio"/> Upper back |
| <input type="radio"/> Thigh | <input type="radio"/> Lower back |
| <input type="radio"/> Knee | <input type="radio"/> Abdominals |
| <input type="radio"/> Calf | <input type="radio"/> Side of the Trunk |
| <input type="radio"/> Shin | <input type="radio"/> Groin |

Which side of your body did this acute injury occur?

Right

☐

Left

☐

Middle

☐

How would you describe this acute injury?

- ☐ Muscle Cramp
- ☐ Muscle Strain
- ☐ Wound/Bruise
- ☐ Ligament strain/rupture
- ☐ Dislocation
- ☐ Fracture
- ☐ Muscle soreness
- ☐ Unidentified pain

What activity were you doing at the time of this acute injury?

- ☐ Bowling
- ☐ Batting
- ☐ Fielding
- ☐ Wicket Keeping
- ☐ Other activity

Which situation did you have this acute injury onset?

- ☐ During a match
- ☐ Pre match warm up
- ☐ After match cool down
- ☐ Team training session
- ☐ Supervised individual training
- ☐ Training alone

How did the doctor or physio term this acute injury? If known, write the medical diagnosis of this acute injury?

medical diagnosis

How many number of days did you miss due to this acute injury? (If none put the number "0")

In season (playing season)

Off season (pre-season)

Did this acute injury reoccur? ("i.e" same body part and same side)

Yes

☐

No

☐

How would you describe this acute recurrent injury?

- ☐ Muscle Cramp
- ☐ Muscle Strain
- ☐ Wound/Bruise
- ☐ Ligament strain/rupture
- ☐ Dislocation
- ☐ Fracture
- ☐ Muscle soreness
- ☐ Unidentified pain

Did you have another acute injury in the past 12 months?

Yes

☐

No

☐

In which body part did you have this acute injury?

- | | |
|------------------------------------|---|
| <input type="radio"/> Shoulder | <input type="radio"/> Ankle & Foot |
| <input type="radio"/> Elbow | <input type="radio"/> Head & Face |
| <input type="radio"/> Forearm | <input type="radio"/> Neck |
| <input type="radio"/> Wrist & Hand | <input type="radio"/> Chest |
| <input type="radio"/> Hip | <input type="radio"/> Upper back |
| <input type="radio"/> Thigh | <input type="radio"/> Lower back |
| <input type="radio"/> Knee | <input type="radio"/> Abdominals |
| <input type="radio"/> Calf | <input type="radio"/> Side of the Trunk |
| <input type="radio"/> Shin | <input type="radio"/> Groin |

Which side of your body did this acute injury occur?

Right

☐

Left

☐

Middle

☐

How would you describe this acute injury?

- ☐ Muscle Cramp
- ☐ Muscle Strain
- ☐ Wound/Bruise
- ☐ Ligament strain/rupture
- ☐ Dislocation
- ☐ Fracture
- ☐ Muscle soreness
- ☐ Unidentified pain

What activity were you doing at the time of this acute injury?

- ☐ Bowling
- ☐ Batting
- ☐ Fielding
- ☐ Wicket Keeping
- ☐ Other activity

Which situation did you have this acute injury onset?

- ☐ During a match
- ☐ Pre match warm up
- ☐ After match cool down
- ☐ Team training session
- ☐ Supervised individual training
- ☐ Training alone

How did the doctor or physio term this acute injury? If known, write the medical diagnosis of this acute injury?

medical diagnosis

How many number of days did you miss due to this injury? (If none put the number "0")

In season (playing season)

Off season (pre-season)

Did this acute injury reoccur? ("i.e" same body part and same side)

Yes

☐

No

☐

How would you describe this recurrent acute injury?

- ☐ Muscle Cramp
- ☐ Muscle Strain
- ☐ Wound/Bruise
- ☐ Ligament strain/rupture
- ☐ Dislocation
- ☐ Fracture
- ☐ Muscle soreness
- ☐ Unidentified pain

Please estimate the total accumulated DAYS during the last 12 months that you were absent from training or matches due to all of your acute injuries

total number of days

SECTION D - OVERUSE INJURIES: Overuse injury is any injury which has caused you pain or is causing you pain during bowling, batting, fielding or anytime during match, training or during exercise workouts. This injury might not have any noticeable external cause of injury. This injury could have gradually caused worsening of pain during or after bowling, matches, training or exercise. Pain would have become worse when loading is continued or may stop you from exercising completely.

Have you had any overuse injuries related to Cricket in the last 12 months?

Yes

☐

No

☐

In which body part did you have this overuse injury?

- | | |
|------------------------------------|---|
| <input type="radio"/> Shoulder | <input type="radio"/> Ankle & Foot |
| <input type="radio"/> Elbow | <input type="radio"/> Head & Face |
| <input type="radio"/> Forearm | <input type="radio"/> Neck |
| <input type="radio"/> Wrist & Hand | <input type="radio"/> Chest |
| <input type="radio"/> Hip | <input type="radio"/> Upper back |
| <input type="radio"/> Thigh | <input type="radio"/> Lower back |
| <input type="radio"/> Knee | <input type="radio"/> Abdominals |
| <input type="radio"/> Calf | <input type="radio"/> Side of the Trunk |
| <input type="radio"/> Shin | <input type="radio"/> Groin |

Which side of your body did this overuse injury occur?

Right

☐

Left

☐

Middle

☐

How would you describe this overuse injury?

- ☐ Stress fracture
- ☐ Tendonitis
- ☐ Bursitis
- ☐ Nerve impingement
- ☐ Other

In what tissue did this overuse injury occur?

- ☐ Muscle
- ☐ Tendon
- ☐ Bone
- ☐ Joint
- ☐ Ligaments
- ☐ Nerve
- ☐ Other soft tissue

How did the doctor or physio term this overuse injury? If known, write the medical diagnosis of this overuse injury?

How many DAYS did you miss due to this overuse injury? (If none put the number "0")

In season (playing season)

Off season (pre season)

Did this overuse injury reoccur? ("i.e" same body part and same side)

Yes

☐

No

☐

In what tissue did this overuse injury reoccur?

- ☐ Muscle
- ☐ Tendon
- ☐ Bone
- ☐ Joint
- ☐ Ligaments
- ☐ Nerve
- ☐ Other soft tissue

Did you have another overuse injury in the past 12 months?

Yes
☐

No
☐

In which body part did you have this overuse injury?

- | | |
|------------------------------------|---|
| <input type="radio"/> Shoulder | <input type="radio"/> Ankle & Foot |
| <input type="radio"/> Elbow | <input type="radio"/> Head & Face |
| <input type="radio"/> Forearm | <input type="radio"/> Neck |
| <input type="radio"/> Wrist & Hand | <input type="radio"/> Chest |
| <input type="radio"/> Hip | <input type="radio"/> Upper back |
| <input type="radio"/> Thigh | <input type="radio"/> Lower back |
| <input type="radio"/> Knee | <input type="radio"/> Abdominals |
| <input type="radio"/> Calf | <input type="radio"/> Side of the Trunk |
| <input type="radio"/> Shin | <input type="radio"/> Groin |

Which side of your body did this overuse injury occur?

Right
☐

Left
☐

Middle
☐

How would you describe this overuse injury?

- ☐ Stress fracture
- ☐ Tendonitis
- ☐ Bursitis
- ☐ Nerve impingement
- ☐ Other

How did the doctor or physio term this overuse injury? If known, write the medical diagnosis of this overuse injury?

In what tissue did this overuse injury occur?

- ☐ Muscle
- ☐ Tendon
- ☐ Bone
- ☐ Joint
- ☐ Ligaments
- ☐ Nerve
- ☐ Other soft tissue

How many DAYS did you miss due to this overuse injury? (If none put the number "0")

In season (playing season)

Off season (pre season)

Did this overuse injury reoccur? ("i.e" same body part and same side)

Yes

☐

No

☐

In what tissue did this overuse injury reoccur?

- ☐ Muscle
- ☐ Tendon
- ☐ Bone
- ☐ Joint
- ☐ Ligaments
- ☐ Nerve
- ☐ Other soft tissue

Did you have another overuse injury in the past 12 months?

Yes

☐

No

☐

In which body part did you have this overuse injury?

- | | |
|------------------------------------|---|
| <input type="radio"/> Shoulder | <input type="radio"/> Ankle & Foot |
| <input type="radio"/> Elbow | <input type="radio"/> Head & Face |
| <input type="radio"/> Forearm | <input type="radio"/> Neck |
| <input type="radio"/> Wrist & Hand | <input type="radio"/> Chest |
| <input type="radio"/> Hip | <input type="radio"/> Upper back |
| <input type="radio"/> Thigh | <input type="radio"/> Lower back |
| <input type="radio"/> Knee | <input type="radio"/> Abdominals |
| <input type="radio"/> Calf | <input type="radio"/> Side of the Trunk |
| <input type="radio"/> Shin | <input type="radio"/> Groin |

Which side of your body did this overuse injury occur ?

Right

☐

Left

☐

Middle

☐

How would you describe this overuse injury?

- ☐ Stress fracture
- ☐ Tendonitis
- ☐ Bursitis
- ☐ Nerve impingement
- ☐ Other

How did the doctor or physio term this overuse injury ? If known, write the medical diagnosis of this overuse injury?

In what tissue did this overuse injury occur ?

- ☐ Muscle
- ☐ Tendon
- ☐ Bone
- ☐ Joint
- ☐ Ligaments
- ☐ Nerve
- ☐ Other soft tissue

How many DAYS did you miss due to this overuse injury? (If none put the number "0")

In season (playing season)

Off season (pre season)

Did this overuse injury reoccur? ("i.e" same body part and same side)

Yes

☐

No

☐

In what tissue did this overuse injury reoccur?

- ☐ Muscle
- ☐ Tendon
- ☐ Bone
- ☐ Joint
- ☐ Ligaments
- ☐ Nerve
- ☐ Other soft tissue

Did you have another overuse injury in the past 12 months?

Yes

☐

No

☐

In which body part did you have this overuse injury?

- | | |
|------------------------------------|---|
| <input type="radio"/> Shoulder | <input type="radio"/> Ankle & Foot |
| <input type="radio"/> Elbow | <input type="radio"/> Head & Face |
| <input type="radio"/> Forearm | <input type="radio"/> Neck |
| <input type="radio"/> Wrist & Hand | <input type="radio"/> Chest |
| <input type="radio"/> Hip | <input type="radio"/> Upper back |
| <input type="radio"/> Thigh | <input type="radio"/> Lower back |
| <input type="radio"/> Knee | <input type="radio"/> Abdominals |
| <input type="radio"/> Calf | <input type="radio"/> Side of the Trunk |
| <input type="radio"/> Shin | <input type="radio"/> Groin |

Which side of your body did this overuse injury occur?

Right
☐

Left
☐

How would you describe this overuse injury?

- ☐ Stress fracture
- ☐ Tendonitis
- ☐ Bursitis
- ☐ Nerve impingement
- ☐ Other

How did the doctor or physio term this overuse injury? If known, write the medical diagnosis of this overuse injury?

In what tissue did your overuse injury occur?

- ☐ Muscle
- ☐ Tendon
- ☐ Bone
- ☐ Joint
- ☐ Ligaments
- ☐ Nerve
- ☐ Other soft tissue

How many DAYS did you miss due to this overuse injury? (If none put the number "0")

In season (playing season)

Off season (pre season)

Did this overuse injury reoccur? ("i.e" same body part and same side)

Yes
☐

No
☐

In what tissue did this overuse injury reoccur?

- ☐ Muscle
- ☐ Tendon
- ☐ Bone
- ☐ Joint
- ☐ Ligaments
- ☐ Nerve
- ☐ Other soft tissue

Please estimate the total accumulated DAYS during the last 12 months that you were absent from training or matches due to your overuse injuries

total number of days

CRICKET BOWLERS INJURY SURVEY

Appendix B- Study 4

- 1. Ethics approval**
- 2. Injury questionnaire**
- 3. Information sheet for participants**
- 4. Consent form**

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2017/55/LR-PS

10 October 2017

Sibi Boycott Noel Walter
Health Sciences
UNIVERSITY OF CANTERBURY

Dear Sibi

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Rotator Cuff Strength and Posterior Shoulder Tightness Assessments Among Cricket Players".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 4th October 2017.

With best wishes for your project.

Yours sincerely

R. Robinson

pp.

Associate Professor Jane Maidment
Chair, Human Ethics Committee

**Rotator cuff strength and
Shoulder range of motion assessments**



Cricket player injury history questionnaire

The purpose of this questionnaire is to collect data about your cricket playing position, playing experience and to find out if you have any current shoulder pain.

1. Date of Birth:
2. Sex:
3. Height_____cm
4. Weight_____kg
5. What is your position in the team? *Please tick the below*

Batsman☐ Wicket keeper☐ Fast bowler☐ Spin bowler☐

6. What is your dominant arm? *Please tick the below*

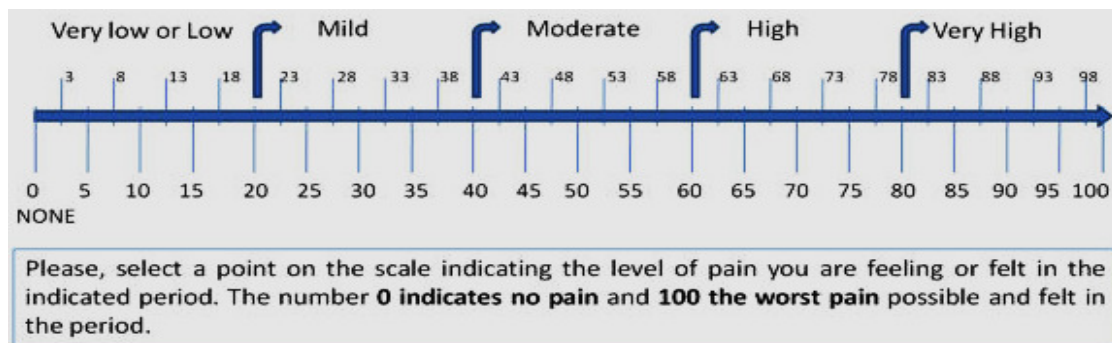
Right☐ Left☐

7. Do you have any current shoulder pain? *Please tick the below*

Yes☐ No☐

8. If you have current shoulder pain, how many months have you played cricket with this shoulder pain?_____months

9. How severe will you rate your shoulder pain?*Please circle the number below*



10. How long have you played cricket at a club level?

_____Years _____months



Information Sheet for Participants

Department: School of Health sciences
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz

Rotator cuff strength and Shoulder range of motion assessments



You are invited to participate in a study to measure your shoulder strength and range of motion.

Researcher info: *My name is Sibi Walter; I'm a sports physiotherapist studying towards a PhD at the University of Canterbury.*

Study purpose: *To measure the shoulder strength and range of motion of the shoulder complex.*

Explanation: I'm looking for participants to be part of a research study which measures your shoulder strength and range of motion. This will be a one-time evaluation which will take ten minutes to complete. You will fill a short questionnaire and I will measure your shoulder range of motion, muscle strength and shoulder capsule tightness. This is a painless non invasive test; it will require you to do some basic shoulder movements in a lying position. This study will quantify the differences in shoulder range of motion and muscle strength between different positions among cricket players.

After reading this information sheet if you would like to participate in this study, please sign the attached consent form and email it back to me at sibi.walter@pg.canterbury.ac.nz.

Participation is voluntary and you have the right to withdraw at any stage. If you withdraw, all your information will be deleted.

The results of the study will be published however all data will be anonymous with only average data used. All the consent forms, shoulder measurement data will be kept in a private password protected computer and the university server will be used to back it up. Data will be coded for maintaining confidentiality and it will be destroyed after 10 years as the HEC principle for a PhD research. The data collected as hard copy will be stored in a locked filing cabinet only the researcher will be having access to them. The study results will be published as part of the PhD thesis and possibly a scientific article in a sports medicine journal. A thesis is a public document and will be available through the UC Library.

Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project.

The project is being carried out *as a requirement for a PhD degree* by Mr. Sibi Walter under the supervision of Dr. Carl Petersen, who can be contacted at carl.petersen@canterbury.ac.nz. They will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return it to the researcher or send it via email to *sibi.walter@pg.canterbury.ac.nz* or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

*Thanks and Regards,
Sibi Walter.*

Consent Form for Participants

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz



Rotator cuff strength and Shoulder range of motion assessments *(Please tick the following)*

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher *Mr. Sibi Walter* and his supervisor *Dr. Carl Petersen* and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after *ten* years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.
- ☐ I understand that I can contact the researcher *Sibi Walter* (sibi.walter@pg.canterbury.ac.nz) or supervisor *Dr. Carl Petersen* (carl.petersen@canterbury.ac.nz) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ I would like a summary of the results of the project.
- ☐ By signing below, I agree to participate in this research project.

Name: _____ Signed: _____ Date: _____

Email address: _____

Please return the form to the researcher or send it via email to sibi.walter@pg.canterbury.ac.nz or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

*Thanks and Regards,
Sibi Walter.*

Appendix C- Study 5

- 1. Ethics approval**
- 2. Information sheet for participants**
- 3. Consent form**

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2017/52/LR-PS

15 September 2017

Sibi Boycott Noel Walter
Health Sciences
UNIVERSITY OF CANTERBURY

Dear Sibi

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Effect of Indian Club Shoulder Exercises on New Zealand Club Cricketers".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 13th September 2017.

With best wishes for your project.

Yours sincerely

R. Robinson

pp.

Associate Professor Jane Maidment
Chair, Human Ethics Committee

Information Sheet for Participants

Department: School of Health sciences
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz



Indian clubs shoulder exercise program

You are invited to participate in a research study investigating the effectiveness of Indian club exercises on improving shoulder strength and range of motion.

Researcher info: *My name is Sibi Walter; I'm a sports physiotherapist studying towards a PhD at the University of Canterbury.*

Study purpose: *To determine the effectiveness of Indian club exercises in improving the strength and range of motion of the shoulder complex.*

Explanation: I'm looking for participants for a shoulder strengthening exercise program using Indian clubs. These wooden clubs shaped similar to bowling pins weigh from 0.5kg to 1.5kg. Using Indian clubs to train the shoulder region has been practised for more than two centuries in the Indian subcontinent. This study will quantify the effectiveness of Indian clubs in increasing the shoulder muscle strength and improving the shoulder range of motion. If you choose to participate, you will undertake a shoulder exercise program three times per week for a total of eight weeks. The exercise program will be demonstrated to you by the researcher and you will also be given diagrams explaining the exercise routine. There will be measurements done at baseline and the 4th and the 6th week of the exercise programme. The testing is painless and will be done to measure your shoulder range of motion and shoulder muscle strength.

After reading this information sheet you can sign the consent form attached to it.

Participation is voluntary and you have the right to withdraw at any stage. If you withdraw, all your information will be deleted.

The results of the study will be published however all data will be anonymous with only average data used. All the consent forms, shoulder measurement data will be kept in a private password protected computer and the university server will be used to back it up. Data will be coded for maintaining confidentiality and it will be destroyed after 10 years as the HEC principle for a PhD research. The data collected as hard copy will be stored in a locked filing cabinet only the researcher will be having access to them. The study results will be published as part of the PhD thesis and possibly a scientific article in a sports medicine journal. A thesis is a public document and will be available through the UC Library.

Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project.

The project is being carried out *as a requirement for a PhD degree* by Mr. Sibi Walter under the supervision of Dr. Carl Petersen, who can be contacted at carl.petersen@canterbury.ac.nz. They will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return it to the researcher or send it via email to *sibi.walter@pg.canterbury.ac.nz* or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

*Thanks and Regards,
Sibi Walter.*

Consent Form for Participants

Department: School of Sport and Physical Education
Telephone: +64 33642506
Email: sibi.walter@pg.canterbury.ac.nz



Indian clubs shoulder exercise program (Please tick the following)

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher *Mr. Sibi Walter* and his supervisor *Dr. Carl Petersen* and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after *ten* years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.
- ☐ I understand that I can contact the researcher *Sibi Walter* (sibi.walter@pg.canterbury.ac.nz) or supervisor *Dr. Carl Petersen* (carl.petersen@canterbury.ac.nz) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ I would like a summary of the results of the project.
- ☐ By signing below, I agree to participate in this research project.

Name: _____ Signed: _____ Date: _____

Email address: _____

Please return the form to the researcher or send it via email to sibi.walter@pg.canterbury.ac.nz or send via post to *Sibi Walter, School of Sport and Physical Education, Kirkwood Avenue, University of Canterbury, Ilam, Christchurch 8041.*

Thanks and Regards,
Sibi Walter.

Appendix D- Study 5

1. Indian clubbell shoulder strengthening exercise programme

CRICKET FAST BOWLERS SHOULDER EXERCISE PROGRAMME

1

WEEK 1 Exercises

DO THIS WORKOUT 3 DAYS PER WEEK (alternative days)

Name:





Date:

Exercise start Time:

NOTE: DO 15 REPS & 3 SETS FOR EACH EXERCISE—1 MINUTE REST PERIOD BETWEEN EXERCISES

PLEASE WATCH THE VIDEO FOR REFERENCE ON HOW TO EXECUTE EACH EXERCISE

Circle the number of sets & write down the number of reps after you complete each exercise in the space provided below

EXERCISE	PICTURE				
WRIST CLOCKWISE & ANTICLOCKWISE ROTATIONS (do right arm first & then left arm)		RIGHT		LEFT	
		SETS	REPS	SETS	REPS
		1		1	
		2		2	
		SETS		REPS	
		1			
		2			
		3			
CIRCLE BOTH ARMS FORWARDS & BACKWARDS (do both arms together)		SETS		REPS	
		1			
		2			
		3			
SQUAT & SWING ARM FORWARDS (do both arms together)		SETS		REPS	
		1			
		2			
		3			

<p>LIFT BOTH ARMS SIDEWAYS TO 90 DEGREES & DO ARM INTERNAL& EXTERNAL ROTATIONS</p> <p><i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr></table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										
<p>UPSIDE DOWN CLUBBELLS HOLD BOTH ARMS SIDE WAYS TO 90DEGREES DO ARM INTERNAL & EXTERNAL ROTATIONS</p> <p><i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr></table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										

SIGNATURE:

Exercise end TIME:

PLEASE KEEP THE SHEETS SAFE & RETURN IT TO SIBI WALTER.

THANKS FOR YOUR SINCERE EFFORT



CRICKET FAST BOWLERS SHOULDER EXERCISE PROGRAMME

WEEK **2** Exercises

DO THIS WORKOUT 3 DAYS PER WEEK (alternative days)

Name:




Date:

Exercise start Time:

NOTE: DO 15 REPS & 3 SETS FOR EACH EXERCISE—1 MINUTE REST PERIOD BETWEEN EXERCISES

PLEASE WATCH THE VIDEO FOR REFERENCE ON HOW TO EXECUTE EACH EXERCISE

Circle the number of sets & write down the number of reps after you complete each exercise in the space provided below

EXERCISE	PICTURE		
<p>RAISE & HOLD BOTH ARMS FORWARD TO 90 DEGREES DO SHOULDER ROTATIONS CLOCKWISE & ANTICLOCKWISE</p> <p><i>(do both arms together)</i></p>		<p>SETS</p> <p>1</p> <p>2</p> <p>3</p>	<p>REPS</p>
<p>RAISE & HOLD BOTH ARMS SIDWAYS TO 90 DEGREES DO SHOULDER ROTATIONS CLOCKWISE & ANTICLOCKWISE</p> <p><i>(do both arms together)</i></p>		<p>SETS</p> <p>1</p> <p>2</p> <p>3</p>	<p>REPS</p>
<p>SHOULDER RETRACTION EXERCISE FOCUS ON PINCHING THE SHOULDER BLADES</p> <p><i>(do both arms together)</i></p>		<p>SETS</p> <p>1</p> <p>2</p> <p>3</p>	<p>REPS</p>

<p>INTERNAL ROTATION OF BOTH ARMS DEFEND FACE & HEAD POSE DO BOTH ARMS SIMULTANEOUSLY</p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr></table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										
<p>UPSIDE DOWN CLUBBELLS HOLD BOTH ARMS SIDE WAYS TO 90DEGREES DO ARM INTERNAL & EXTERNAL ROTATIONS <i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr></table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										
<p>UPSIDE DOWN CLUBBELLS HOLD BOTH ARMS FORWARD TO 90DEGREES DO ARM INTERNAL & EXTERNAL ROTATIONS <i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr></table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										

SIGNATURE:

Exercise end TIME:

PLEASE KEEP THE SHEETS SAFE & RETURN IT TO SIBI WALTER.

THANKS FOR YOUR SINCERE EFFORT



CRICKET FAST BOWLERS SHOULDER EXERCISE PROGRAMME

3

WEEK Exercises

DO THIS WORKOUT 3 DAYS PER WEEK (alternative days)

Name:





Date:




Exercise start Time:

NOTE: DO 15 REPS & 3 SETS FOR EACH EXERCISE—1 MINUTE REST PERIOD BETWEEN EXERCISES

PLEASE WATCH THE VIDEO FOR REFERENCE ON HOW TO EXECUTE EACH EXERCISE

Circle the number of sets & write down the number of reps after you complete each exercise in the space provided below

EXERCISE	PICTURE				
<p>START WITH ONE ARM FRONT HIT, SWING AROUND HEAD & FINISH BY SIDE HIT</p> <p>(do right arm first & then left arm)</p>		RIGHT		LEFT	
		SETS	REPS	SETS	REPS
		1		1	
		2		2	
		3		3	
<p>SINGLE ARM SWING COMBO</p> <p>start sideways- swing inside- take behind head & finish sideways</p> <p>(do right arm first & then left arm)</p>		RIGHT		LEFT	
		SETS	REPS	SETS	REPS
		1		1	
		2		2	
		3		3	
<p>BOTH ARMS SWING COMBO</p> <p>hold both arms sideways- swing inside- take behind head & finish sideways</p> <p>(do both arms together)</p>		SETS		REPS	
		1			
		2			
		3			
<p>ALTERNATE ARM SWING COMBO</p> <p>Take both clubs- start sideways with one arm - swing inside- take behind head & finish sideways then alternate to other arm</p> <p>(do both arms together)</p>		SETS		REPS	
		1			
		2			
		3			

<p>BOTH ARMS SWING COMBO & FULL CIRCLE do the both arm swing combo & finish with a full circle (do both arms together)</p>		<table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr> <td>1</td> <td></td> </tr> <tr> <td>2</td> <td></td> </tr> <tr> <td>3</td> <td></td> </tr> </tbody> </table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										
<p>FOLLOW THE EXERCISES FROM WEEK ONE & TWO – PLEASE WATCH WEEK ONE & TWO VIDEOS FOR REFERENCE These exercises are taken from week one & two</p>										
<p>CIRCLE BOTH ARMS FORWARDS & BACKWARDS (do both arms together)</p>		<table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr> <td>1</td> <td></td> </tr> <tr> <td>2</td> <td></td> </tr> <tr> <td>3</td> <td></td> </tr> </tbody> </table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										
<p>SHOULDER RETRACTION EXERCISE FOCUS ON PINCHING THE SHOULDER BLADES (do both arms together)</p>		<table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr> <td>1</td> <td></td> </tr> <tr> <td>2</td> <td></td> </tr> <tr> <td>3</td> <td></td> </tr> </tbody> </table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										

SIGNATURE:

Exercise end TIME:

PLEASE KEEP THE SHEETS SAFE & RETURN IT TO SIBI WALTER.

THANKS FOR YOUR SINCERE EFFORT



CRICKET FAST BOWLERS SHOULDER EXERCISE PROGRAMME

4

WEEK Exercises

DO THIS WORKOUT 3 DAYS PER WEEK (alternative days)

Name:




Date:

Exercise start Time:

NOTE: DO 8 REPS & 4 SETS FOR EACH EXERCISE—1 MINUTE REST PERIOD BETWEEN EXERCISES

PLEASE WATCH THE VIDEO FOR REFERENCE ON HOW TO EXECUTE EACH EXERCISE

Circle the number of sets & write down the number of reps after you complete each exercise in the space provided below

EXERCISE	PICTURE																						
<p>FOLLOW THE EXERCISES FROM WEEK ONE & TWO – PLEASE WATCH WEEK ONE & TWO VIDEOS FOR REFERENCE</p> <p>These exercises are taken from week one & two</p>																							
<p>START WITH ONE ARM FRONT HIT, SWING AROUND HEAD & FINISH BY SIDE HIT</p> <p>(do right arm first & then left arm)</p>		<p>RIGHT</p> <table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr><td>1</td><td></td></tr> <tr><td>2</td><td></td></tr> <tr><td>3</td><td></td></tr> <tr><td>4</td><td></td></tr> </tbody> </table>	SETS	REPS	1		2		3		4		<p>LEFT</p> <table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr><td>1</td><td></td></tr> <tr><td>2</td><td></td></tr> <tr><td>3</td><td></td></tr> <tr><td>4</td><td></td></tr> </tbody> </table>	SETS	REPS	1		2		3		4	
SETS	REPS																						
1																							
2																							
3																							
4																							
SETS	REPS																						
1																							
2																							
3																							
4																							
<p>SINGLE ARM SWING COMBO</p> <p>start sideways- swing inside- take behind head & finish sideways</p> <p>(do right arm first & then left arm)</p>		<p>RIGHT</p> <table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr><td>1</td><td></td></tr> <tr><td>2</td><td></td></tr> <tr><td>3</td><td></td></tr> <tr><td>4</td><td></td></tr> </tbody> </table>	SETS	REPS	1		2		3		4		<p>LEFT</p> <table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr><td>1</td><td></td></tr> <tr><td>2</td><td></td></tr> <tr><td>3</td><td></td></tr> <tr><td>4</td><td></td></tr> </tbody> </table>	SETS	REPS	1		2		3		4	
SETS	REPS																						
1																							
2																							
3																							
4																							
SETS	REPS																						
1																							
2																							
3																							
4																							
<p>BOTH ARMS SWING COMBO</p> <p>hold both arms sideways- swing inside- take behind head & finish sideways</p> <p>(do both arms together)</p>		<p>SETS</p> <table border="1"> <tbody> <tr><td>1</td></tr> <tr><td>2</td></tr> <tr><td>3</td></tr> <tr><td>4</td></tr> </tbody> </table>	1	2	3	4	<p>REPS</p> <table border="1"> <tbody> <tr><td></td></tr> <tr><td></td></tr> <tr><td></td></tr> <tr><td></td></tr> </tbody> </table>																
1																							
2																							
3																							
4																							

<p>CIRCLE BOTH ARMS FORWARDS & BACKWARDS</p> <p><i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr><tr><td>4</td><td></td></tr></table>	SETS	REPS	1		2		3		4	
SETS	REPS											
1												
2												
3												
4												
<p>SHOULDER RETRACTION EXERCISE FOCUS ON PINCHING THE SHOULDER BLADES</p> <p><i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr><tr><td>4</td><td></td></tr></table>	SETS	REPS	1		2		3		4	
SETS	REPS											
1												
2												
3												
4												
<p>INTERNAL ROTATION OF BOTH ARMS DEFEND FACE & HEAD POSE DO BOTH ARMS SIMULTANEOUSLY</p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr><tr><td>4</td><td></td></tr></table>	SETS	REPS	1		2		3		4	
SETS	REPS											
1												
2												
3												
4												

SIGNATURE:

Exercise end TIME:

PLEASE KEEP THE SHEETS SAFE & RETURN IT TO SIBI WALTER.

THANKS FOR YOUR SINCERE EFFORT



CRICKET FAST BOWLERS SHOULDER EXERCISE PROGRAMME

WEEK 5 Exercises

DO THIS WORKOUT 3 DAYS PER WEEK (alternative days)

Name:

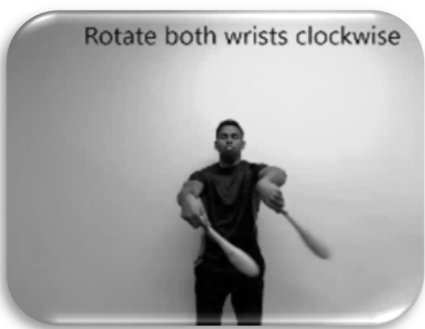


Date:



Exercise start Time:

NOTE: TRY COMPLETING 10 REPS & 4 SETS FOR EACH EXERCISE—1 MINUTE REST PERIOD BETWEEN EXERCISES

PLEASE WATCH WEEK ONE, TWO & THREE VIDEOS FOR REFERENCE

Circle the number of sets & write down the number of reps after you complete each exercise in the space provided below

EXERCISE	PICTURE		
BOTH WRISTS ROTATIONS CLOCKWISE & ANTICLOCKWISE <i>(do both wrists at the same time)</i>		SETS REPS	
		1	
		2	
		3	
		4	
BOTH ARMS SWING COMBO hold both arms sideways- swing inside- take behind head & finish sideways <i>(do both arms together)</i>		SETS REPS	
		1	
		2	
		3	
		4	
SQUAT & SWING ARM FORWARDS <i>(do both arms together)</i>		SETS REPS	
		1	
		2	
		3	
		4	

<p>LIFT BOTH ARMS SIDEWAYS TO 90 DEGREES & DO ARM INTERNAL& EXTERNAL ROTATIONS</p> <p><i>(do both arms together)</i></p>		<table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr><td>1</td><td></td></tr> <tr><td>2</td><td></td></tr> <tr><td>3</td><td></td></tr> <tr><td>4</td><td></td></tr> </tbody> </table>	SETS	REPS	1		2		3		4	
SETS	REPS											
1												
2												
3												
4												
<p>UPSIDE DOWN CLUBBELLS HOLD BOTH ARMS FORWARD TO 90DEGREES DO ARM INTERNAL & EXTERNAL ROTATIONS</p> <p><i>(do both arms together)</i></p>		<table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr><td>1</td><td></td></tr> <tr><td>2</td><td></td></tr> <tr><td>3</td><td></td></tr> <tr><td>4</td><td></td></tr> </tbody> </table>	SETS	REPS	1		2		3		4	
SETS	REPS											
1												
2												
3												
4												
<p>RAISE & HOLD BOTH ARMS SIDEWAYS TO 90 DEGREES DO SHOULDER ROTATIONS CLOCKWISE & ANTICLOCKWISE</p> <p><i>(do both arms together)</i></p>		<table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr><td>1</td><td></td></tr> <tr><td>2</td><td></td></tr> <tr><td>3</td><td></td></tr> <tr><td>4</td><td></td></tr> </tbody> </table>	SETS	REPS	1		2		3		4	
SETS	REPS											
1												
2												
3												
4												
<p>INTERNAL ROTATION OF BOTH ARMS DEFEND FACE & HEAD POSE DO BOTH ARMS SIMULTANEOUSLY</p>		<table border="1"> <thead> <tr> <th>SETS</th> <th>REPS</th> </tr> </thead> <tbody> <tr><td>1</td><td></td></tr> <tr><td>2</td><td></td></tr> <tr><td>3</td><td></td></tr> <tr><td>4</td><td></td></tr> </tbody> </table>	SETS	REPS	1		2		3		4	
SETS	REPS											
1												
2												
3												
4												

SIGNATURE:

Exercise end TIME:

PLEASE KEEP THE SHEETS SAFE & RETURN IT TO SIBI WALTER.

THANKS FOR YOUR SINCERE EFFORT



CRICKET FAST BOWLERS SHOULDER EXERCISE PROGRAMME

WEEK Exercises

DO THIS WORKOUT 3 DAYS PER WEEK (alternative days)

Name:

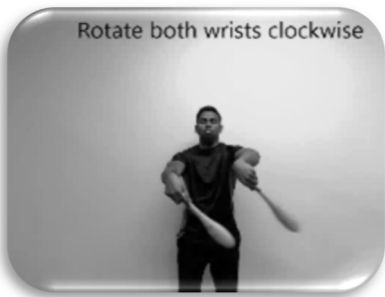


Date:


Exercise start Time:

NOTE: TRY COMPLETING 12 REPS & 3 SETS FOR EACH EXERCISE—1 MINUTE REST PERIOD BETWEEN EXERCISES

PLEASE WATCH WEEK ONE, TWO & THREE VIDEOS FOR REFERENCE

Circle the number of sets & write down the number of reps after you complete each exercise in the space provided below

EXERCISE	PICTURE		
<p>BOTH WRISTS ROTATIONS CLOCKWISE & ANTICLOCKWISE</p> <p>(do both wrists at the same time)</p>	<p>Rotate both wrists clockwise</p> 	<p>SETS</p> <p>1</p> <p>2</p> <p>3</p>	<p>REPS</p>
<p>CIRCLE BOTH ARMS FORWARDS & BACKWARDS</p> <p>(do both arms together)</p>		<p>SETS</p> <p>1</p> <p>2</p> <p>3</p>	<p>REPS</p>
<p>RAISE & HOLD BOTH ARMS FORWARD TO 90 DEGREES DO SHOULDER ROTATIONS CLOCKWISE & ANTICLOCKWISE</p> <p>(do both arms together)</p>		<p>SETS</p> <p>1</p> <p>2</p> <p>3</p>	<p>REPS</p>

<p>HOLD BOTH ARMS FORWARD & DO ARM INTERNAL & EXTERNAL ROTATIONS</p> <p><i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr></table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										
<p>UPSIDE DOWN CLUBBELLS HOLD BOTH ARMS SIDEWAYS TO 90DEGREES DO ARM INTERNAL & EXTERNAL ROTATIONS</p> <p><i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr></table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										
<p>SHOULDER RETRACTION EXERCISE FOCUS ON PINCHING THE SHOULDER BLADES</p> <p><i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr></table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										
<p>ALTERNATE ARM SWING COMBO</p> <p>Take both clubs- start sideways with one arm - swing inside- take behind head & finish sideways then alternate to other arm</p> <p><i>(do both arms together)</i></p>		<table><tr><th>SETS</th><th>REPS</th></tr><tr><td>1</td><td></td></tr><tr><td>2</td><td></td></tr><tr><td>3</td><td></td></tr></table>	SETS	REPS	1		2		3	
SETS	REPS									
1										
2										
3										

SIGNATURE:

Exercise end TIME:

PLEASE KEEP THE SHEETS SAFE & RETURN IT TO SIBI WALTER.

THANKS FOR YOUR SINCERE EFFORT



